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(54) **ORGANIC ELECTROLUMINESCENT MATERIALS AND DEVICES**

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**H01L 51/56** (2006.01)

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CPC ..... **H01L 51/0067** (2013.01); **C07D 487/04** (2013.01); **C07F 15/0033** (2013.01); **C09K 11/025** (2013.01); **C09K 11/06** (2013.01); **H01L 51/0072** (2013.01); **H01L 51/0085** (2013.01); **C09K 2211/185** (2013.01); **H01L 51/0005** (2013.01); **H01L 51/0097** (2013.01); **H01L 51/5004** (2013.01); **H01L 51/506** (2013.01); **H01L 51/5016** (2013.01); **H01L 51/5076** (2013.01); **H01L 51/5096** (2013.01); **H01L 51/56** (2013.01)

(58) **Field of Classification Search**

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2211/185; H01L 51/0032; H01L 51/005; H01L 51/0005; H01L 51/0072; H01L 51/0073; H01L 51/0074; H01L 51/0085; H01L 51/0067; H01L 51/50; H01L 51/5004; H01L 51/506; H01L 51/5076; H01L 51/5012; H01L 51/5016; H01L 51/0097; H01L 51/56; H01L 51/5096  
USPC ..... 428/690, 691, 917, 411.4, 336; 427/58, 427/66; 313/500-512; 257/40, 88-104, 257/E51.001-E51.052; 252/301.16-301.35

See application file for complete search history.

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(57) **ABSTRACT**

A composition of matter that includes a novel combination of host compounds containing indol-fused hosts and emissive dopants containing benzofuran or azabenzofuran ligand is disclosed.

**17 Claims, 2 Drawing Sheets**

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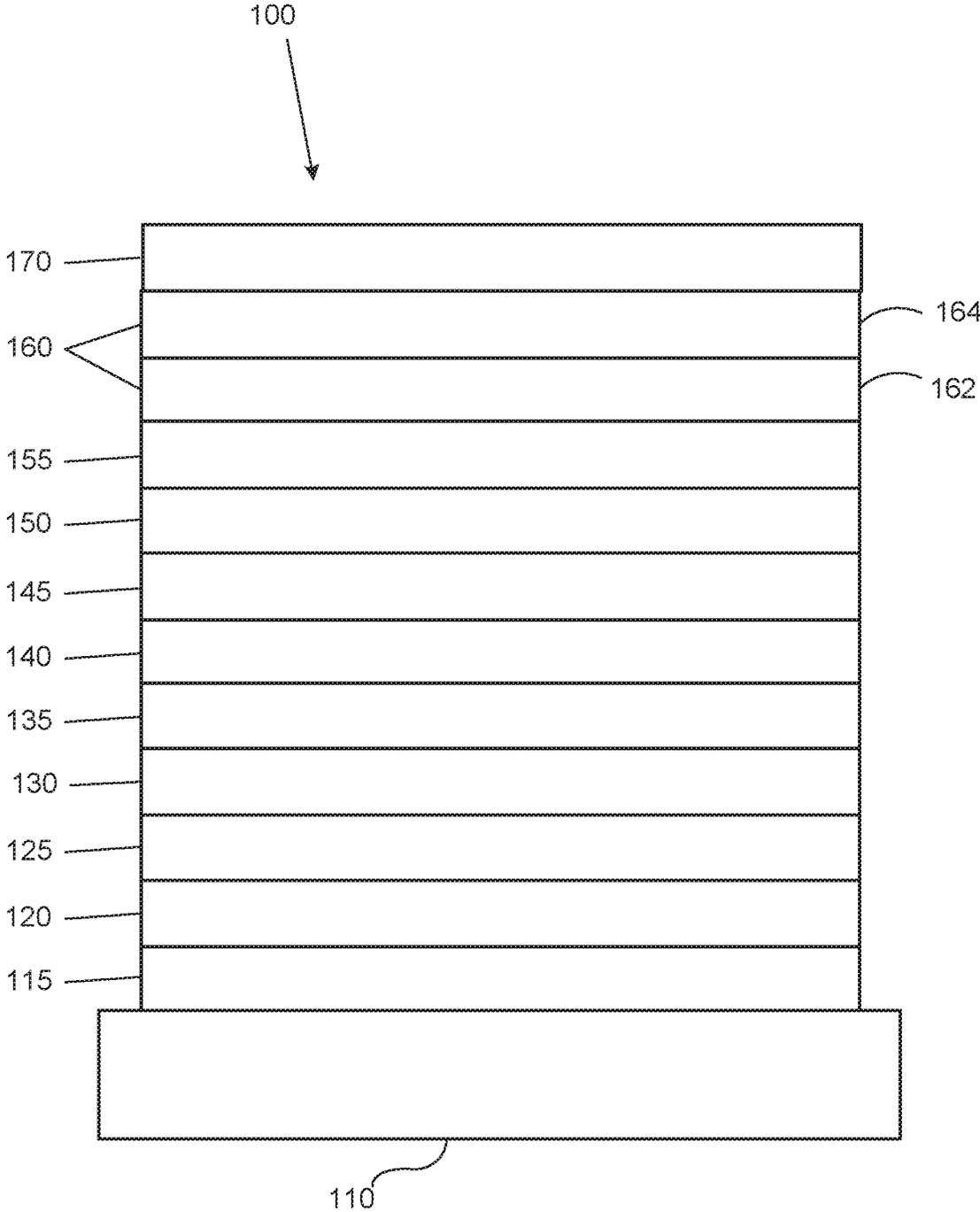


FIGURE 1

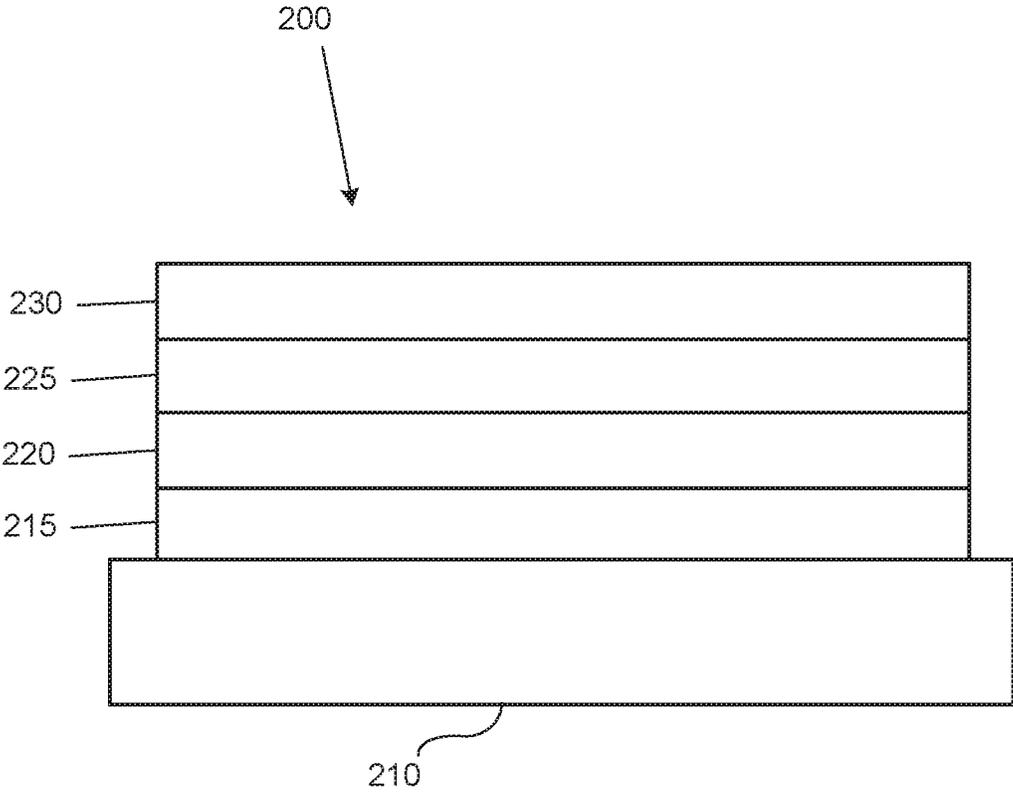


FIGURE 2

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**ORGANIC ELECTROLUMINESCENT  
MATERIALS AND DEVICES****CROSS-REFERENCE TO RELATED  
APPLICATIONS**

This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Applications Ser. No. 62/216,113, filed Sep. 9, 2015 and 62/240,256, filed Oct. 12, 2015, the entire contents of which is incorporated herein by reference.

**PARTIES TO A JOINT RESEARCH  
AGREEMENT**

The claimed invention was made by, on behalf of and/or in connection with one or more of the following parties to a joint university corporation research agreement: The Regents of the University of Michigan, Princeton University, University of Southern California, and the Universal Display Corporation. The agreement was in effect on and before the date the claimed invention was made, and the claimed invention was made as a result of activities undertaken within the scope of the agreement.

**FIELD**

The present invention relates to compositions of matter that comprise a novel combination of host compounds containing indol-fused hosts and emissive dopants containing benzofuran or azabenzofuran ligand.

**BACKGROUND**

Opto-electronic devices that make use of organic materials are becoming increasingly desirable for a number of reasons. Many of the materials used to make such devices are relatively inexpensive, so organic opto-electronic devices have the potential for cost advantages over inorganic devices. In addition, the inherent properties of organic materials, such as their flexibility, may make them well suited for particular applications such as fabrication on a flexible substrate. Examples of organic opto-electronic devices include organic light emitting diodes/devices (OLEDs), organic phototransistors, organic photovoltaic cells, and organic photodetectors. For OLEDs, the organic materials may have performance advantages over conventional materials. For example, the wavelength at which an organic emissive layer emits light may generally be readily tuned with appropriate dopants.

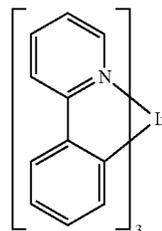
OLEDs make use of thin organic films that emit light when voltage is applied across the device. OLEDs are becoming an increasingly interesting technology for use in applications such as flat panel displays, illumination, and backlighting. Several OLED materials and configurations are described in U.S. Pat. Nos. 5,844,363, 6,303,238, and 5,707,745, which are incorporated herein by reference in their entirety.

One application for phosphorescent emissive molecules is a full color display. Industry standards for such a display call for pixels adapted to emit particular colors, referred to as "saturated" colors. In particular, these standards call for saturated red, green, and blue pixels. Alternatively the OLED can be designed to emit white light. In conventional liquid crystal displays emission from a white backlight is filtered using absorption filters to produce red, green and blue emission. The same technique can also be used with OLEDs. The white OLED can be either a single EML device

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or a stack structure. Color may be measured using CV coordinates, which are well known to the art.

One example of a green emissive molecule is tris(2-phenylpyridine) iridium, denoted Ir(ppy)<sub>3</sub>, which has the following structure:



In this, and later figures herein, we depict a dative bond from nitrogen to metal (here, Ir) as a straight line.

As used herein, the term "organic" includes polymeric materials as well as small molecule organic materials that may be used to fabricate organic opto-electronic devices. "Small molecule" refers to any organic material that is nota polymer, and "small molecules" may actually be quite large. Small molecules may include repeat units in some circumstances. For example, using a long chain alkyl group as a substituent does not remove a molecule from the "small molecule" class. Small molecules may also be incorporated into polymers, for example as a pendent group on a polymer backbone or as a part of the backbone. Small molecules may also serve as the core moiety of a dendrimer, which consists of a series of chemical shells built on the core moiety. The core moiety of a dendrimer may be a fluorescent or phosphorescent small molecule emitter. A dendrimer may be a "small molecule," and it is believed that all dendrimers currently used in the field of OLEDs are small molecules.

As used herein, "top" means furthest away from the substrate, while "bottom" means closest to the substrate. Where a first layer is described as "disposed over" a second layer, the first layer is disposed further away from substrate. There may be other layers between the first and second layer, unless it is specified that the first layer is "in contact with" the second layer. For example, a cathode may be described as "disposed over" an anode, even though there are various organic layers in between.

As used herein, "solution processible" means capable of being dissolved, dispersed, or transported in and/or deposited from a liquid medium, either in solution or suspension form.

A ligand may be referred to as "photoactive" when it is believed that the ligand directly contributes to the photoactive properties of an emissive material. A ligand may be referred to as "ancillary" when it is believed that the ligand does not contribute to the photoactive properties of an emissive material, although an ancillary ligand may alter the properties of a photoactive ligand.

As used herein, and as would be generally understood by one skilled in the art, a first "Highest Occupied Molecular Orbital" (HOMO) or "Lowest Unoccupied Molecular Orbital" (LUMO) energy level is "greater than" or "higher than" a second HOMO or LUMO energy level if the first energy level is closer to the vacuum energy level. Since ionization potentials (IP) are measured as a negative energy relative to a vacuum level, a higher HOMO energy level corresponds to an IP having a smaller absolute value (an IP that is less negative). Similarly, a higher LUMO energy level

corresponds to an electron affinity (EA) having a smaller absolute value (an EA that is less negative). On a conventional energy level diagram, with the vacuum level at the top, the LUMO energy level of a material is higher than the HOMO energy level of the same material. A “higher” HOMO or LUMO energy level appears closer to the top of such a diagram than a “lower” HOMO or LUMO energy level.

As used herein, and as would be generally understood by one skilled in the art, a first work function is “greater than” or “higher than” a second work function if the first work function has a higher absolute value. Because work functions are generally measured as negative numbers relative to vacuum level, this means that a “higher” work function is more negative. On a conventional energy level diagram, with the vacuum level at the top, a “higher” work function is illustrated as further away from the vacuum level in the downward direction. Thus, the definitions of HOMO and LUMO energy levels follow a different convention than work functions.

More details on OLEDs, and the definitions described above, can be found in U.S. Pat. No. 7,279,704, which is incorporated herein by reference in its entirety.

In the state of the art OLED devices, the emissive layer (EML) may consist of three or more components. In one example, the EML can consist of two host-type compounds and an emitter combination (e.g. a hole transporting cohost (h-host), an electron transporting cohost (e-host), and a compound capable of functioning as an emitter in an OLED at room temperature). In another example, the EML can consist of one host-type compound and two emitter-type compounds (e.g., a host compound and two compounds each capable of functioning as an emitter in an OLED at room temperature). Conventionally, in order to fabricate such EMU having three or more components using vacuum thermal evaporation (VTE) process, three or more evaporation sources are required, one for each of the components. Because the concentration of the components are important for the device performance, typically, the rate of deposition of each component is measured individually during the deposition process. This makes the VTE process complicated and costly compared to a standard two-component EML with a single host and an emitter, which requires only two evaporation sources.

Premixing two or more materials and evaporating them from one VTE sublimation crucible can reduce the number of VTE evaporation sources and simplify the fabrication process. In order for materials to be premixable into an evaporation source, they should co-evaporate and deposit uniformly without changing the ratio. The ratio of the components in the mixture should be the same as the ratio of the components in the evaporation deposited films from these premixed materials. Therefore, the concentration of the two components in the deposited film is controlled by their concentration in the premixed evaporation source. Variations in the film’s composition may adversely affect the device performance. In order to obtain a stable co-evaporation from a mixture of compounds under vacuum, one would assume that the materials must have the same evaporation temperature under the same condition. However, this may not be the only parameter one has to consider. When two compounds are mixed together, they may interact with each other and the evaporation property of the mixture may differ from their individual properties. On the other hand, materials with slightly different evaporation temperatures may form a stable co-evaporation mixture. Therefore, it is extremely difficult to achieve a stable co-evaporation mixture.

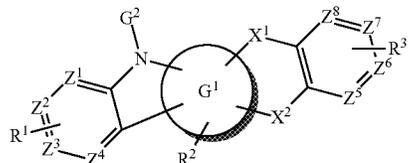
So far, there have been very few stable co-evaporation mixture examples. “Evaporation temperature” of a material is measured in a vacuum deposition tool at a constant pressure, normally between  $1 \times 10^{-7}$  Torr to  $1 \times 10^{-8}$  Torr, at a 2 Å/sec deposition rate on a surface positioned at a set distance away from the evaporation source of the material being evaporated, e.g. sublimation crucible in a VTE tool. The various measured values such as temperature, pressure, deposition rate, etc. disclosed herein are expected to have nominal variations because of the expected tolerances in the measurements that produced these quantitative values as understood by one of ordinary skill in the art.

Many factors other than temperature can contribute to the ability to achieve stable co-evaporation, such as the miscibility of the different materials and the phase transition temperatures of the different materials. The inventors found that when two materials have similar evaporation temperatures, and similar mass loss rate or similar vapor pressures, the two materials can co-evaporate percently. “Mass loss rate” of a material is defined as the percentage of mass lost over time (“percentage/minute” or “%/min”) and is determined by measuring the time it takes to lose the first 10% of the mass of a sample of the material as measured by thermal gravity analysis (TGA) under a given experimental condition at a given constant temperature for a given material after the a steady evaporation state is reached. The given constant temperature is one temperature point that is chosen so that the value of mass loss rate is between about 0.05 to 0.50%/min. One of ordinary skill in this field should appreciate that in order to compare two parameters, the experimental condition should be consistent. The method of measuring mass loss rate and vapor pressure is well known in the art and can be found, for example, in Bull. et al. Mater. Sci. 2011, 34, 7.

A proper combination of host materials and emissive dopant in the emissive layer is important to achieve excellent performance of OLEDs. When an indo-fused compound is used as host and metal complex with benzofuran or azabenzofuran ligand is used as emissive dopant, the OLED device exhibits an unexpectedly high efficiency and long lifetime.

## SUMMARY

According to an embodiment, a composition of material comprising a mixture of a first compound and a second compound is disclosed. The first compound has the structure of Formula I



wherein  $G^1$  is a six-member aromatic ring;

wherein  $X^1$  and  $X^2$  are each independently selected from the group consisting of direct bond,  $CR^4R^5$ ,  $NR^6$ , O, S and Se;

wherein at least one of  $X^1$  and  $X^2$  is not a direct bond;

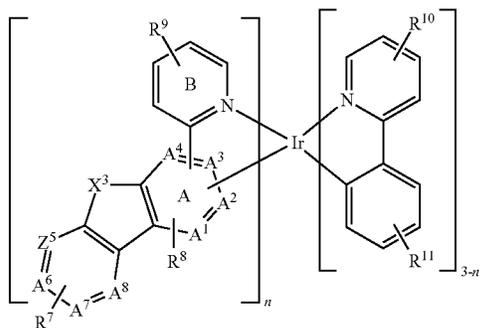
wherein  $Z^1$  to  $Z^8$  are each independently selected from the group consisting of nitrogen and carbon;

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wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $G^2$ ,  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$  and  $R^6$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein any two adjacent substituents can optionally join or fuse into a ring;

wherein the second compound has a formula  $Ir(L_A)_n(L_B)_{3-n}$ , having the structure according to Formula II:



wherein each  $A^1$ ,  $A^2$ ,  $A^3$ ,  $A^4$ ,  $A^5$ ,  $A^6$ ,  $A^7$ , and  $A^8$  comprise carbon or nitrogen;

wherein ring B is bonded to ring A through a C—C bond; wherein the iridium is bonded to ring A through a Ir—C bond;

wherein  $X^3$  is selected from a group consisting of O, S and Se;

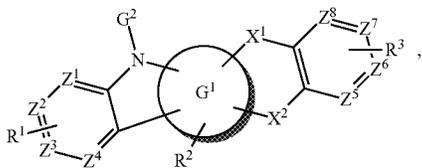
wherein  $R^7$  to  $R^{11}$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $R^7$  to  $R^{11}$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof;

wherein any two adjacent substituents can optionally join or fuse into a ring; and

wherein  $n$  is an integer from 1 to 3.

According to another embodiment, an organic light emitting diode/device (OLED) is also provided. The OLED can include an anode; a cathode; and an organic layer, disposed between the anode and the cathode, comprising a composition of materials comprising a mixture of a first compound and a second compound, wherein the first compound has the structure of Formula I



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wherein  $G^1$  is a six-member aromatic ring;

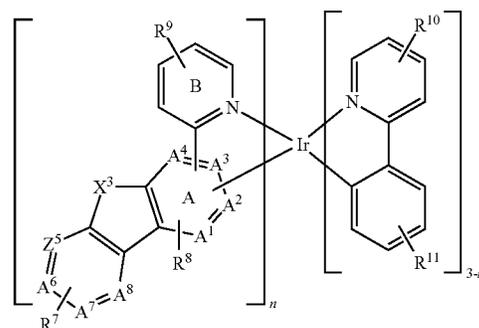
wherein  $X^1$  and  $X^2$  are each independently selected from the group consisting of direct bond,  $CR^4R^5$ ,  $NR^6$ , O, S and Se;

wherein at least one of  $X^1$  and  $X^2$  is not a direct bond; wherein  $Z^1$  to  $Z^8$  are each independently selected from the group consisting of nitrogen and carbon;

wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $G^2$ ,  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$  and  $R^6$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein any two adjacent substituents can optionally join or fuse into a ring;

wherein the second compound has a formula  $Ir(L_A)_n(L_B)_{3-n}$ , and having the structure according to Formula II



wherein each  $A^1$ ,  $A^2$ ,  $A^3$ ,  $A^4$ ,  $A^5$ ,  $A^6$ ,  $A^7$ , and  $A^8$  comprise carbon or nitrogen;

wherein ring B is bonded to ring A through a C—C bond; wherein the iridium is bonded to ring A through a Ir—C bond;

wherein  $X^3$  is selected from a group consisting of O, S and Se;

wherein  $R^7$  to  $R^{11}$  each independently represent mono to the possible maximum number of substitution, or no substitution;

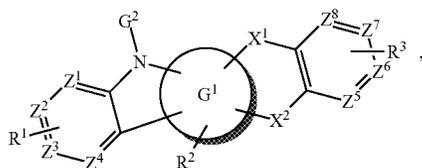
wherein  $R^7$  to  $R^{11}$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, sulfanyl, sulfonyl, phosphino, and combinations thereof; and wherein any two adjacent substituents can optionally join or fuse into a ring; and wherein  $n$  is an integer from 1 to 3.

According to yet another embodiment, a method for fabricating an OLED is disclosed. The method comprises: providing a substrate having a first electrode disposed thereon;

depositing a first organic layer over the first electrode by evaporating a mixture of a first compound and a second compound in a vacuum deposition tool at a constant pressure between  $1 \times 10^{-6}$  Torr to  $1 \times 10^{-9}$  Torr, at a 2 Å/sec deposition rate on a surface position at a predefined distance away from the mixture being evaporated; and

depositing a second electrode over the first organic layer; wherein the first compound has the structure of Formula I

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wherein  $G^1$  is a six-member aromatic ring;

wherein  $X^1$  and  $X^2$  are each independently selected from the group consisting of direct bond,  $CR^4R^5$ ,  $NR^6$ , O, S and Se;

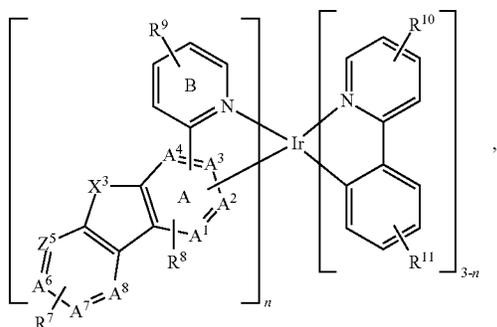
wherein at least one of  $X^1$  and  $X^2$  is not a direct bond;

wherein  $Z^1$  to  $Z^8$  are each independently selected from the group consisting of nitrogen and carbon;

wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $G^2$ ,  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$  and  $R^6$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein any two adjacent substituents can optionally join or fuse into a ring;

wherein the second compound has a formula  $Ir(L_A)_n(L_B)_{3-n}$ , and having the structure according to Formula II



wherein each  $A^1$ ,  $A^2$ ,  $A^3$ ,  $A^4$ ,  $A^5$ ,  $A^6$ ,  $A^7$ , and  $A^8$  comprise carbon or nitrogen;

wherein ring B is bonded to ring A through a C—C bond;

wherein the iridium is bonded to ring A through a Ir—C bond;

wherein  $X^3$  is selected from a group consisting of O, S and Se;

wherein  $R^7$  to  $R^{11}$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $R^7$  to are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and

wherein any two adjacent substituents can optionally join or fuse into a ring; and

wherein n is an integer from 1 to 3.

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## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an organic light emitting device.

FIG. 2 shows an inverted organic light emitting device that does not have a separate electron transport layer.

## DETAILED DESCRIPTION

Generally, an OLED comprises at least one organic layer disposed between and electrically connected to an anode and a cathode. When a current is applied, the anode injects holes and the cathode injects electrons into the organic layer(s). The injected holes and electrons each migrate toward the oppositely charged electrode. When an electron and hole localize on the same molecule, an “exciton,” which is a localized electron-hole pair having an excited energy state, is formed. Light is emitted when the exciton relaxes via a photoemissive mechanism. In some cases, the exciton may be localized on an excimer or an exciplex. Non-radiative mechanisms, such as thermal relaxation, may also occur, but are generally considered undesirable.

The initial OLEDs used emissive molecules that emitted light from their singlet states (“fluorescence”) as disclosed, for example, in U.S. Pat. No. 4,769,292, which is incorporated by reference in its entirety. Fluorescent emission generally occurs in a time frame of less than 10 nanoseconds.

More recently, OLEDs having emissive materials that emit light from triplet states (“phosphorescence”) have been demonstrated. Baldo et al., “Highly Efficient Phosphorescent Emission from Organic Electroluminescent Devices,” *Nature*, vol. 395, 151-154, 1998; (“Baldo-I”) and Baldo et al., “Very high-efficiency green organic light-emitting devices based on electrophosphorescence,” *Appl. Phys. Lett.*, vol. 75, No. 3, 4-6 (1999) (“Baldo-II”), are incorporated by reference in their entireties. Phosphorescence is described in more detail in U.S. Pat. No. 7,279,704 at cols. 5-6, which are incorporated by reference.

FIG. 1 shows an organic light emitting device 100. The figures are not necessarily drawn to scale. Device 100 may include a substrate 110, an anode 115, a hole injection layer 120, a hole transport layer 125, an electron blocking layer 130, an emissive layer 135, a hole blocking layer 140, an electron transport layer 145, an electron injection layer 150, a protective layer 155, a cathode 160, and a barrier layer 170. Cathode 160 is a compound cathode having a first conductive layer 162 and a second conductive layer 164. Device 100 may be fabricated by depositing the layers described, in order. The properties and functions of these various layers, as well as example materials, are described in more detail in U.S. Pat. No. 7,279,704 at cols. 6-10, which are incorporated by reference.

More examples for each of these layers are available. For example, a flexible and transparent substrate-anode combination is disclosed in U.S. Pat. No. 5,844,363, which is incorporated by reference in its entirety. An example of a p-doped hole transport layer is m-MTDATA doped with  $F_4$ -TCNQ at a molar ratio of 50:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. Examples of emissive and host materials are disclosed in U.S. Pat. No. 6,303,238 to Thompson et al., which is incorporated by reference in its entirety. An example of an n-doped electron transport layer is BPhen doped with Li at a molar ratio of 1:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. U.S. Pat. Nos. 5,703,436 and 5,707,745, which are incorporated by reference in their entireties, disclose examples of cathodes including compound cathodes having a thin layer of metal such as Mg:Ag with an overlying transparent, electrically-

conductive, sputter-deposited ITO layer. The theory and use of blocking layers is described in more detail in U.S. Pat. No. 6,097,147 and U.S. Patent Application Publication No. 2003/0230980, which are incorporated by reference in their entireties. Examples of injection layers are provided in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety. A description of protective layers may be found in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety.

FIG. 2 shows an inverted OLED 200. The device includes a substrate 210, a cathode 215, an emissive layer 220, a hole transport layer 225, and an anode 230. Device 200 may be fabricated by depositing the layers described, in order. Because the most common OLED configuration has a cathode disposed over the anode, and device 200 has cathode 215 disposed under anode 230, device 200 may be referred to as an "inverted" OLED. Materials similar to those described with respect to device 100 may be used in the corresponding layers of device 200. FIG. 2 provides one example of how some layers may be omitted from the structure of device 100.

The simple layered structure illustrated in FIGS. 1 and 2 is provided by way of non-limiting example, and it is understood that embodiments of the invention may be used in connection with a wide variety of other structures. The specific materials and structures described are exemplary in nature, and other materials and structures may be used. Functional OLEDs may be achieved by combining the various layers described in different ways, or layers may be omitted entirely, based on design, performance, and cost factors. Other layers not specifically described may also be included. Materials other than those specifically described may be used. Although many of the examples provided herein describe various layers as comprising a single material, it is understood that combinations of materials, such as a mixture of host and dopant, or more generally a mixture, may be used. Also, the layers may have various sublayers. The names given to the various layers herein are not intended to be strictly limiting. For example, in device 200, hole transport layer 225 transports holes and injects holes into emissive layer 220, and may be described as a hole transport layer or a hole injection layer. In one embodiment, an OLED may be described as having an "organic layer" disposed between a cathode and an anode. This organic layer may comprise a single layer, or may further comprise multiple layers of different organic materials as described, for example, with respect to FIGS. 1 and 2.

Structures and materials not specifically described may also be used, such as OLEDs comprised of polymeric materials (PLEDs) such as disclosed in U.S. Pat. No. 5,247,190 to Friend et al., which is incorporated by reference in its entirety. By way of further example, OLEDs having a single organic layer may be used. OLEDs may be stacked, for example as described in U.S. Pat. No. 5,707,745 to Forrest et al, which is incorporated by reference in its entirety. The OLED structure may deviate from the simple layered structure illustrated in FIGS. 1 and 2. For example, the substrate may include an angled reflective surface to improve out-coupling, such as a mesa structure as described in U.S. Pat. No. 6,091,195 to Forrest et al., and/or a pit structure as described in U.S. Pat. No. 5,834,893 to Bulovic et al., which are incorporated by reference in their entireties.

Unless otherwise specified, any of the layers of the various embodiments may be deposited by any suitable method. For the organic layers, preferred methods include thermal evaporation, ink-jet, such as described in U.S. Pat.

Nos. 6,013,982 and 6,087,196, which are incorporated by reference in their entireties, organic vapor phase deposition (OVPD), such as described in U.S. Pat. No. 6,337,102 to Forrest et al., which is incorporated by reference in its entirety, and deposition by organic vapor jet printing (OVJP), such as described in U.S. Pat. No. 7,431,968, which is incorporated by reference in its entirety. Other suitable deposition methods include spin coating and other solution based processes. Solution based processes are preferably carried out in nitrogen or an inert atmosphere. For the other layers, preferred methods include thermal evaporation. Preferred patterning methods include deposition through a mask, cold welding such as described in U.S. Pat. Nos. 6,294,398 and 6,468,819, which are incorporated by reference in their entireties, and patterning associated with some of the deposition methods such as ink-jet and OVJP. Other methods may also be used. The materials to be deposited may be modified to make them compatible with a particular deposition method. For example, substituents such as alkyl and aryl groups, branched or unbranched, and preferably containing at least 3 carbons, may be used in small molecules to enhance their ability to undergo solution processing. Substituents having 20 carbons or more may be used, and 3-20 carbons is a preferred range. Materials with asymmetric structures may have better solution processibility than those having symmetric structures, because asymmetric materials may have a lower tendency to recrystallize. Dendrimer substituents may be used to enhance the ability of small molecules to undergo solution processing.

Devices fabricated in accordance with embodiments of the present invention may further optionally comprise a barrier layer. One purpose of the barrier layer is to protect the electrodes and organic layers from damaging exposure to harmful species in the environment including moisture, vapor and/or gases, etc. The barrier layer may be deposited over, under or next to a substrate, an electrode, or over any other parts of a device including an edge. The barrier layer may comprise a single layer, or multiple layers. The barrier layer may be formed by various known chemical vapor deposition techniques and may include compositions having a single phase as well as compositions having multiple phases. Any suitable material or combination of materials may be used for the barrier layer. The barrier layer may incorporate an inorganic or an organic compound or both. The preferred barrier layer comprises a mixture of a polymeric material and a non-polymeric material as described in U.S. Pat. No. 7,968,146, PCT Pat. Application Nos. PCT/US2007/023098 and PCT/US2009/042829, which are herein incorporated by reference in their entireties. To be considered a "mixture", the aforesaid polymeric and non-polymeric materials comprising the barrier layer should be deposited under the same reaction conditions and/or at the same time. The weight ratio of polymeric to non-polymeric material may be in the range of 95:5 to 5:95. The polymeric material and the non-polymeric material may be created from the same precursor material. In one example, the mixture of a polymeric material and a non-polymeric material consists essentially of polymeric silicon and inorganic silicon.

Devices fabricated in accordance with embodiments of the invention can be incorporated into a wide variety of electronic component modules (or units) that can be incorporated into a variety of electronic products or intermediate components. Examples of such electronic products or intermediate components include display screens, lighting devices such as discrete light source devices or lighting panels, etc. that can be utilized by the end-user product

manufacturers. Such electronic component modules can optionally include the driving electronics and/or power source(s). Devices fabricated in accordance with embodiments of the invention can be incorporated into a wide variety of consumer products that have one or more of the electronic component modules or units) incorporated therein. Such consumer products would include any kind of products that include one or more light source(s) and/or one or more of some type of visual displays. Some examples of such consumer products include flat panel displays, computer monitors, medical monitors, televisions, billboards, lights for interior or exterior illumination and/or signaling, heads-up displays, fully or partially transparent displays, flexible displays, laser printers, telephones, cell phones, tablets, phablets, personal digital assistants (PDAs), wearable device, laptop computers, digital cameras, camcorders, viewfinders, micro-displays, 3-D displays, vehicles, a large area wall, theater or stadium screen, or a sign. Various control mechanisms may be used to control devices fabricated in accordance with the present invention, including passive matrix and active matrix. Many of the devices are intended for use in a temperature range comfortable to humans, such as 18 degrees C. to 30 degrees C., and more preferably at room temperature (20-25 degrees C.), but could be used outside this temperature range, for example, from -40 degree C. to +80 degree C.

The materials and structures described herein may have applications in devices other than OLEDs. For example, other optoelectronic devices such as organic solar cells and organic photodetectors may employ the materials and structures. More generally, organic devices, such as organic transistors, may employ the materials and structures.

The term "halo," "halogen," or "halide" as used herein includes fluorine, chlorine, bromine, and iodine.

The term "alkyl" as used herein contemplates both straight and branched chain alkyl radicals. Preferred alkyl groups are those containing from one to fifteen carbon atoms and includes methyl, ethyl, propyl, 1-methylethyl, butyl, 1-methylpropyl, 2-methylpropyl, pentyl, 1-methylbutyl, 2-methyl butyl, 3-methylbutyl, 1,1-dimethylpropyl, 1,2-dimethylpropyl, 2,2-dimethylpropyl, and the like. Additionally, the alkyl group may be optionally substituted.

The term "cycloalkyl" as used herein contemplates cyclic alkyl radicals. Preferred cycloalkyl groups are those containing 3 to 10 ring carbon atoms and includes cyclopropyl, cyclopentyl, cyclohexyl, adamantyl, and the like. Additionally, the cycloalkyl group may be optionally substituted.

The term "alkenyl" as used herein contemplates both straight and branched chain alkene radicals. Preferred alkenyl groups are those containing two to fifteen carbon atoms. Additionally, the alkenyl group may be optionally substituted.

The term "alkynyl" as used herein contemplates both straight and branched chain alkyne radicals. Preferred alkynyl groups are those containing two to fifteen carbon atoms. Additionally, the alkynyl group may be optionally substituted.

The terms "aralkyl" or "arylalkyl" as used herein are used interchangeably and contemplate an alkyl group that has as a substituent an aromatic group. Additionally, the aralkyl group may be optionally substituted.

The term "heterocyclic group" as used herein contemplates aromatic and non-aromatic cyclic radicals. Hetero-aromatic cyclic radicals also means heteroaryl. Preferred hetero-non-aromatic cyclic groups are those containing 3 to 7 ring atoms which includes at least one hetero atom, and includes cyclic amines such as morpholino, piperdino, pyr-

rolidino, and the like, and cyclic ethers, such as tetrahydrofuran, tetrahydropyran, and the like. Additionally, the heterocyclic group may be optionally substituted.

The term "aryl" or "aromatic group" as used herein contemplates single-ring groups and polycyclic ring systems. The polycyclic rings may have two or more rings in which two carbons are common to two adjoining rings (the rings are "fused") wherein at least one of the rings is aromatic, e.g., the other rings can be cycloalkyls, cycloalkenyls, aryl, heterocycles, and/or heteroaryls. Preferred aryl groups are those containing six to thirty carbon atoms, preferably six to twenty carbon atoms, more preferably six to twelve carbon atoms. Especially preferred is an aryl group having six carbons, ten carbons or twelve carbons. Suitable aryl groups include phenyl, biphenyl, triphenyl, triphenylene, tetraphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, and azulene, preferably phenyl, biphenyl, triphenyl, triphenylene, fluorene, and naphthalene. Additionally, the aryl group may be optionally substituted.

The term "heteroaryl" as used herein contemplates single-ring hetero-aromatic groups that may include from one to five heteroatoms. The term heteroaryl also includes polycyclic hetero-aromatic systems having two or more rings in which two atoms are common to two adjoining rings (the rings are "fused") wherein at least one of the rings is a heteroaryl, e.g., the other rings can be cycloalkyls, cycloalkenyls, aryl, heterocycles, and/or heteroaryls. Preferred heteroaryl groups are those containing three to thirty carbon atoms, preferably three to twenty carbon atoms, more preferably three to twelve carbon atoms. Suitable heteroaryl groups include dibenzothiophene, benzofuran, benzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofurodipyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine, preferably dibenzothiophene, benzofuran, dibenzoselenophene, carbazole, indolocarbazole, imidazole, pyridine, triazine, benzimidazole, 1,2-azaborine, 1,3-azaborine, 1,4-azaborine, borazine, and aza-analogs thereof. Additionally, the heteroaryl group may be optionally substituted.

The alkyl, cycloalkyl, alkenyl, alkynyl, aralkyl, heterocyclic group, aryl, and heteroaryl may be unsubstituted or may be substituted with one or more substituents selected from the group consisting of deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, cyclic amino, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ether, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

As used herein, "substituted" indicates that a substituent other than H is bonded to the relevant position, such as carbon. Thus, for example, where R<sup>1</sup> is mono-substituted, then one R<sup>1</sup> must be other than H. Similarly, where R<sup>1</sup> is di-substituted, then two of R<sup>1</sup> must be other than H. Similarly, where R<sup>1</sup> is unsubstituted, R<sup>1</sup> is hydrogen for all available positions.

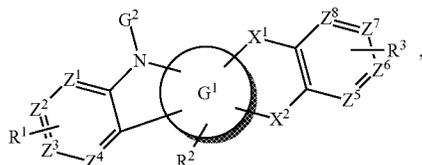
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The “aza” designation in the fragments described herein, i.e. aza-dibenzofuran, aza-dibenzothiophene, etc. means that one or more of the C—H groups in the respective fragment can be replaced by a nitrogen atom, for example, and without any limitation, azatriphenylene encompasses both dibenzo[f,h]quinoxalline and dibenzo[f,h]quinoline. One of ordinary skill in the art can readily envision other nitrogen analogs of the aza-derivatives described above, and all such analogs are intended to be encompassed by the terms as set forth herein.

It is to be understood that when a molecular fragment is described as being a substituent or otherwise attached to another moiety, its name may be written as if it were a fragment (e.g. phenyl, phenylene, naphthyl, dibenzofuryl) or as if it were the whole molecule (e.g. benzene, naphthalene, dibenzofuran). As used herein, these different ways of designating a substituent or attached fragment are considered to be equivalent.

A novel combination of host compounds containing indol-fused hosts and emissive dopants containing benzofuran or azabenzofuran ligand is disclosed. It was found that this combination of host and dopant provides outstanding performance compared to other compounds reported in the literature.

According to an aspect of the present disclosure, a composition of material comprising a mixture of a first compound and a second compound is described. The first compound has the structure of Formula I



wherein  $G^1$  is a six-member aromatic ring;

wherein  $X^1$  and  $X^2$  are each independently selected from the group consisting of direct bond,  $CR^4R^5$ ,  $NR^6$ , O, S and Se;

wherein at least one of  $X^1$  and  $X^2$  is not a direct bond;

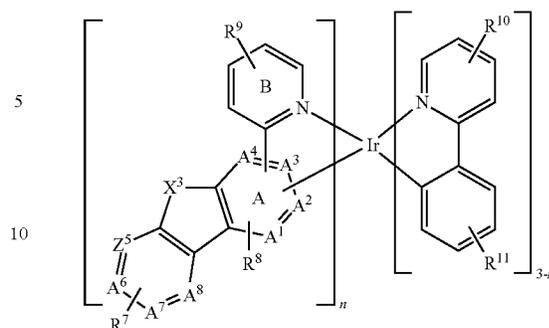
wherein  $Z^1$  to  $Z^8$  are each independently selected from the group consisting of nitrogen and carbon;

wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $G^2$ ,  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$  and  $R^6$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein any two adjacent substituents can optionally join or fuse into a ring;

wherein the second compound has a formula  $Ir(L_A)_n(L_B)_B)_{3-n}$ , and having the structure according to Formula II

## 14



wherein each  $A^1$ ,  $A^2$ ,  $A^3$ ,  $A^4$ ,  $A^5$ ,  $A^6$ ,  $A^7$ , and  $A^8$  comprise carbon or nitrogen;

wherein ring B is bonded to ring A through a C—C bond;

wherein the iridium is bonded to ring A through a Ir—C bond;

wherein  $X^3$  is selected from a group consisting of O, S and Se;

wherein  $R^7$  to  $R^{11}$  each independently represent mono to the possible maximum number of substitution, or no substitution;

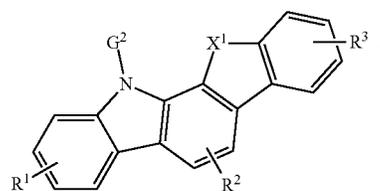
wherein  $R^7$  to  $R^{11}$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof;

wherein any two adjacent substituents can optionally join or fuse into a ring; and

wherein  $n$  is an integer from 1 to 3.

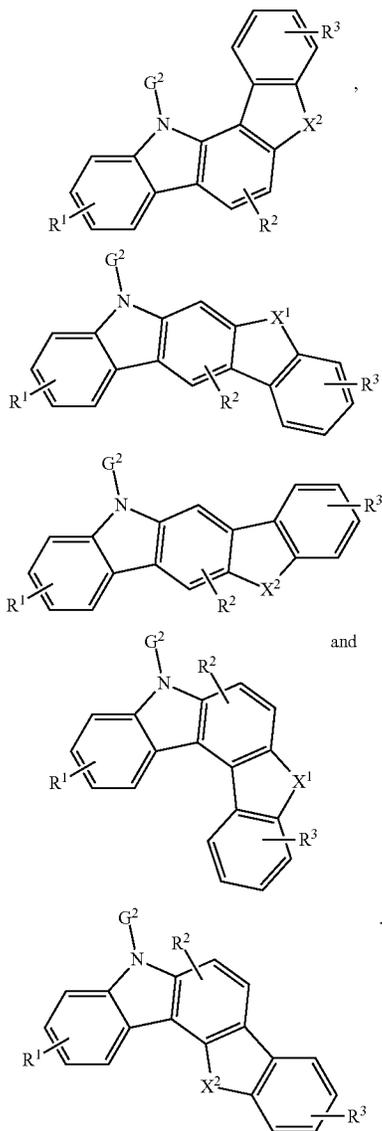
In some embodiments of the composition of material,  $X^1$  is  $NR^6$ ,  $X^2$  is direct bond. In some embodiments of the composition of material, at least one of  $G^2$  and  $R^6$  comprises a triazine group. In some embodiments of the composition of material,  $G^2$  is aryl or heteroaryl group which can be further substituted. In some embodiments of the composition of material,  $G^2$  is selected from the group consisting of phenyl, biphenyl, terphenyl, dibenzofuran, dibenzothiophene, dibenzoselenophene, fluorene, triphenylene, and combinations thereof. In some embodiments of the composition of material,  $G^2$  is selected from the group consisting of pyridine, pyrimidine, pyrazine, triazine, quinoline, isoquinoline, quinazoline, phenanthroline, azadibenzofuran, azadibenzothiophene, azadibenzoselenophene, azafluorene, azatriphenylene, and combinations thereof. In some embodiments of the composition of material,  $Z^1$  to  $Z^8$  are each a carbon.

In some embodiments of the composition of material, the first compound is selected from the group consisting of:



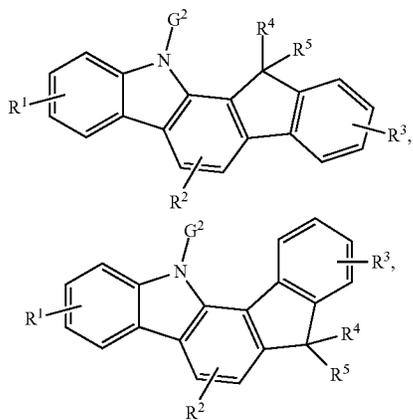
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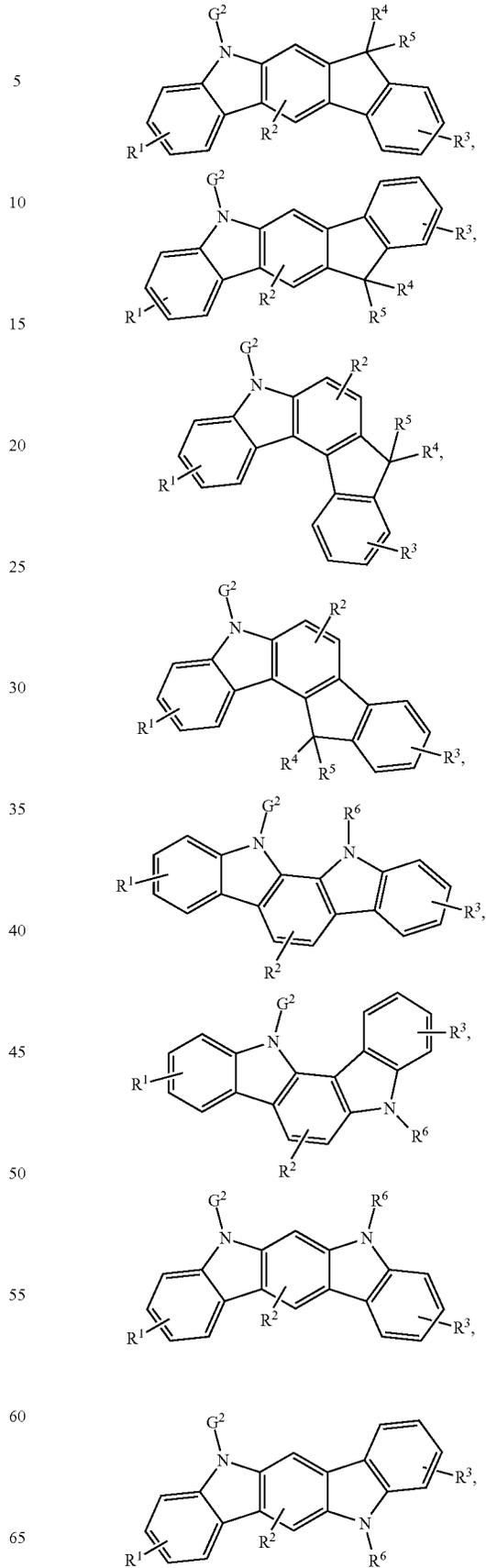
and

In some embodiments of the composition of the first compound is selected from the group consisting of:



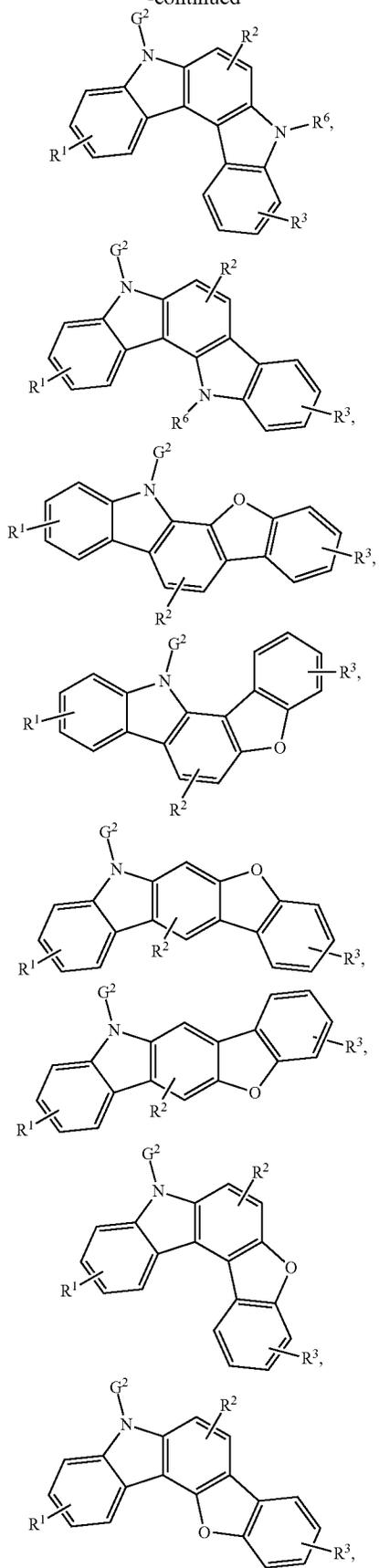
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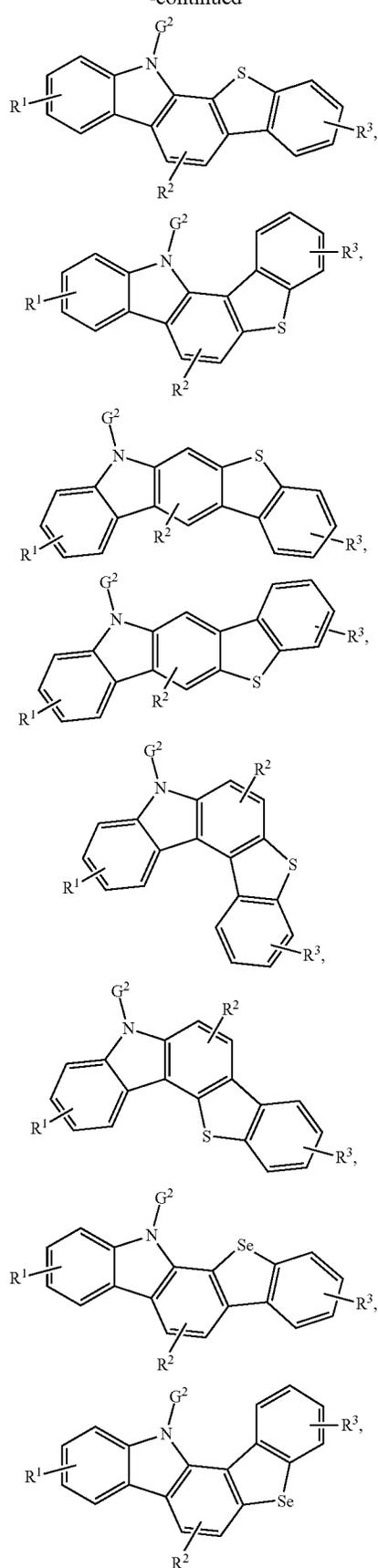
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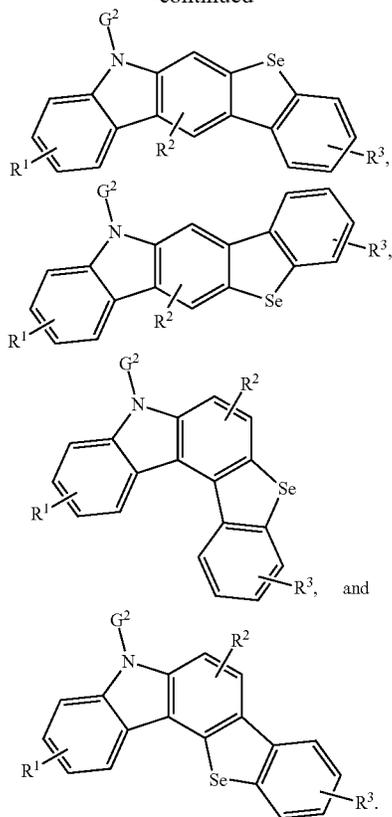
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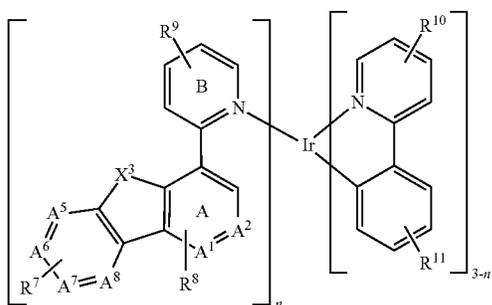


In some embodiments of the composition of material, n in Formula II is 1.

In some embodiments of the composition of material,  $A^1$  to  $A^8$  in Formula II are carbon. In some embodiments, at least one of  $A^1$  to  $A^8$  is nitrogen.

In some embodiments of the composition of material, the second compound has the formula:

Formula III



In some embodiments of the composition of material,  $X^3$  in Formula II is O.

In some embodiments of the composition of material,  $R^7$  to  $R^{11}$  in Formula II are each independently selected from the group consisting of hydrogen, deuterium, alkyl, cycloalkyl, and combinations thereof.

In some embodiments,  $R^9$  in Formula II is alkyl or cycloalkyl. In some embodiments,  $R^9$  in Formula II is selected from the group consisting of aryl, substituted aryl, heteroaryl, and substituted heteroaryl.

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In some embodiments of the composition of material, the second compound has  $L_A$  selected from the group consisting of:

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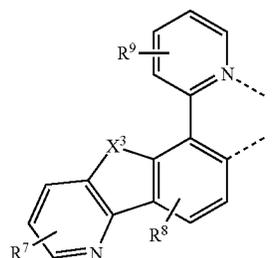
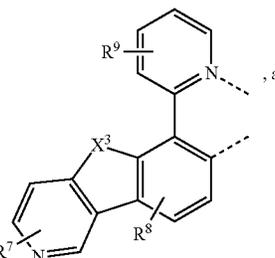
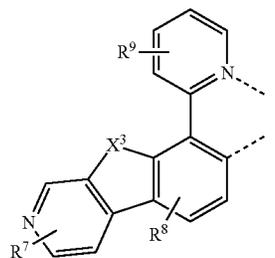
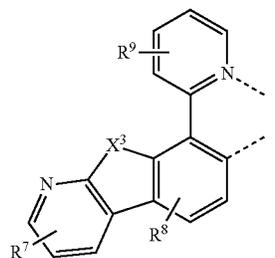
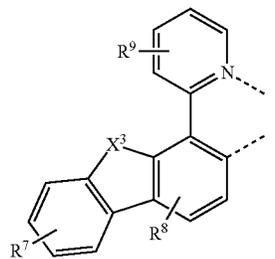
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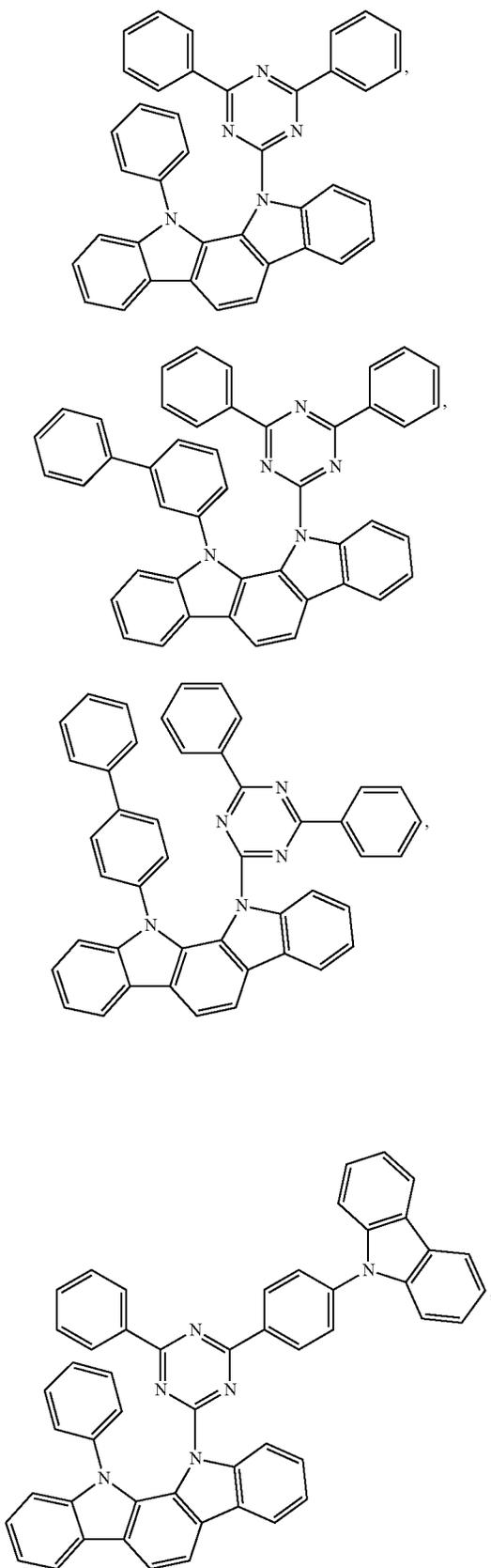
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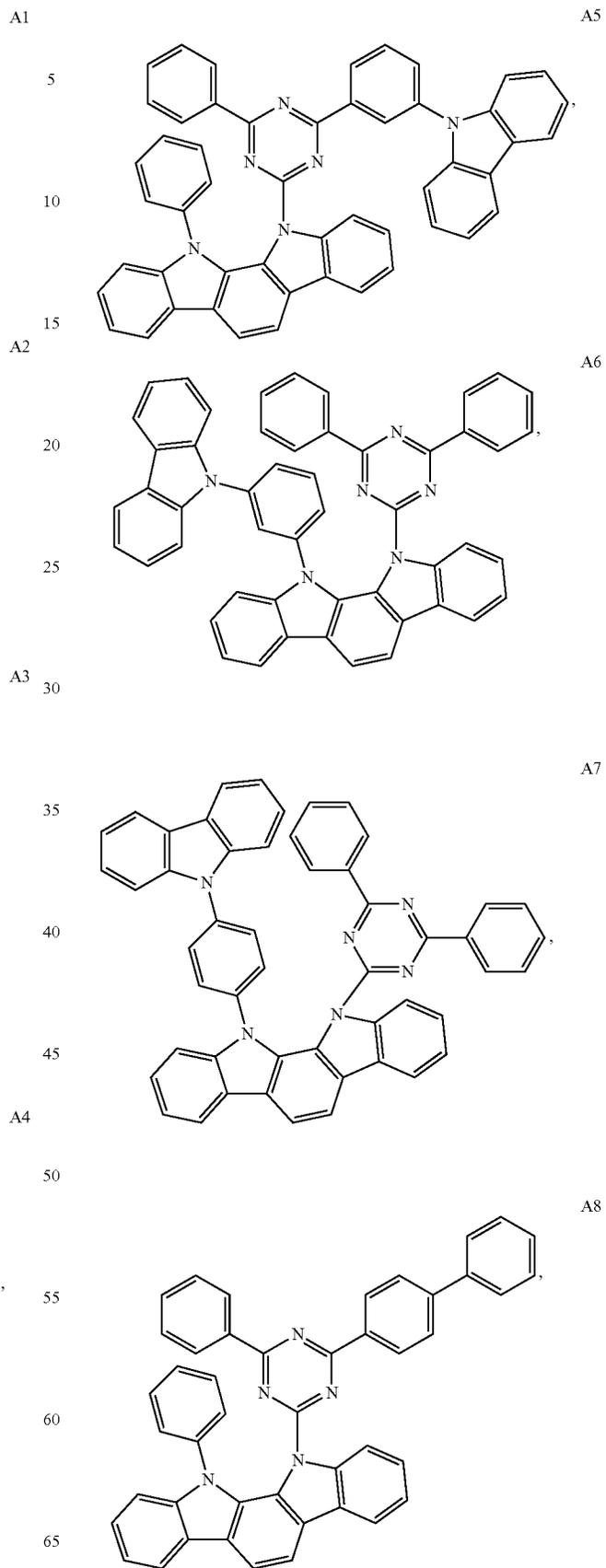
In some embodiments of the composition of material, the first compound is selected from the group consisting of:

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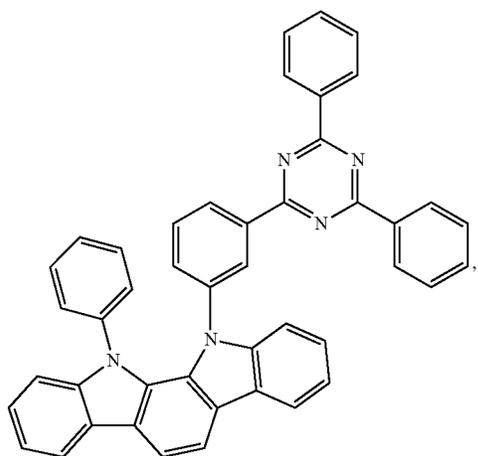
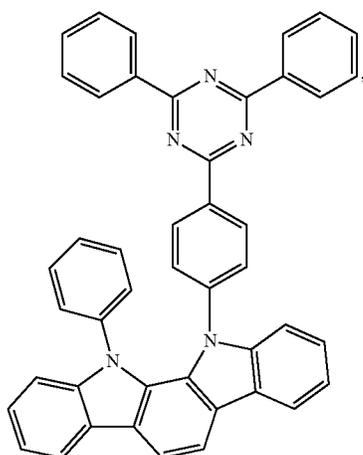
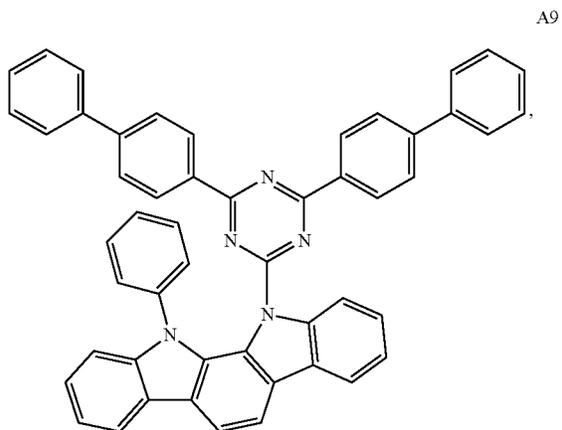


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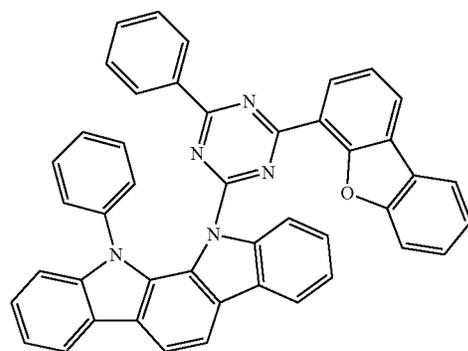
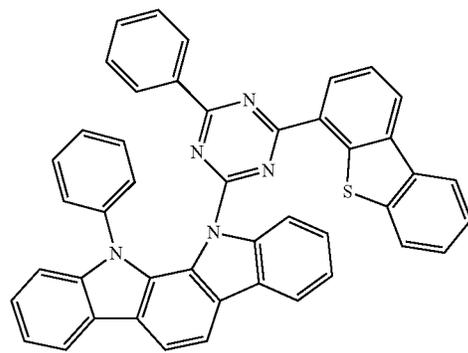
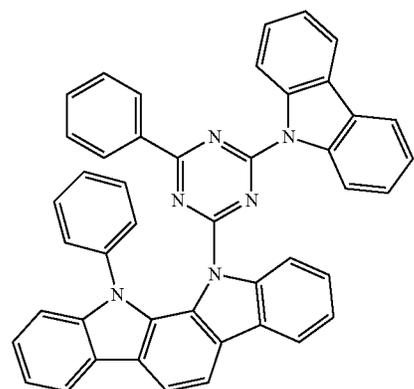
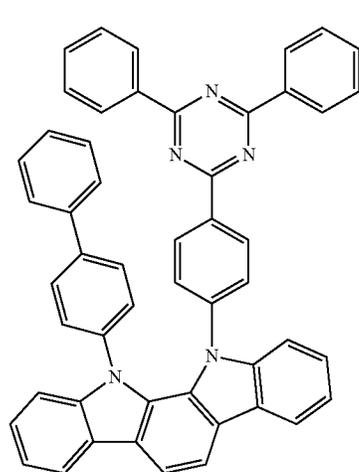
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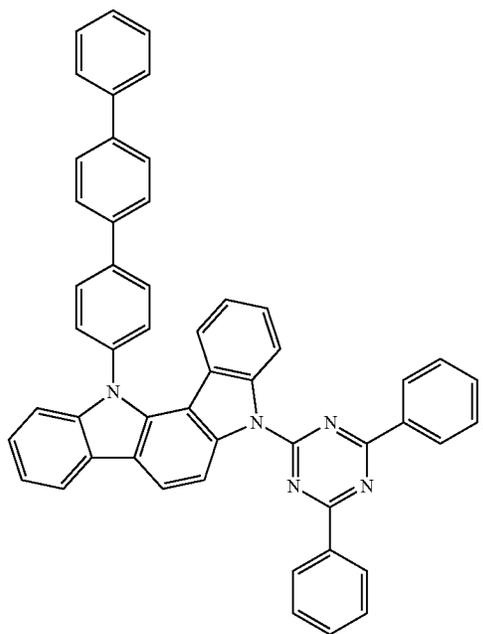
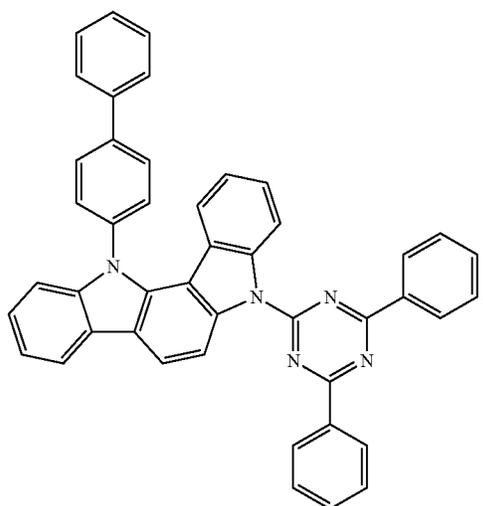
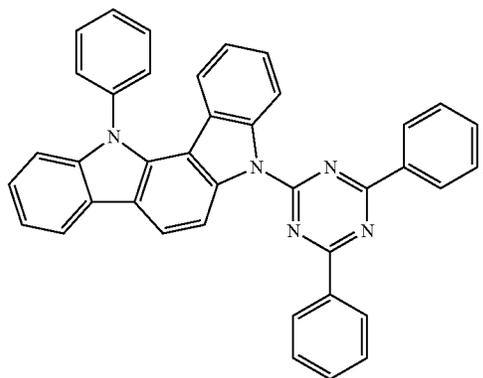


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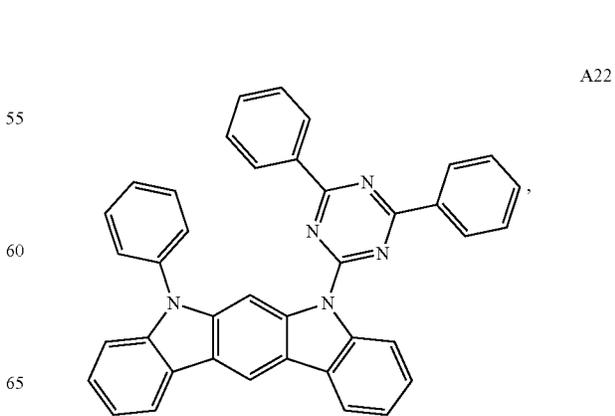
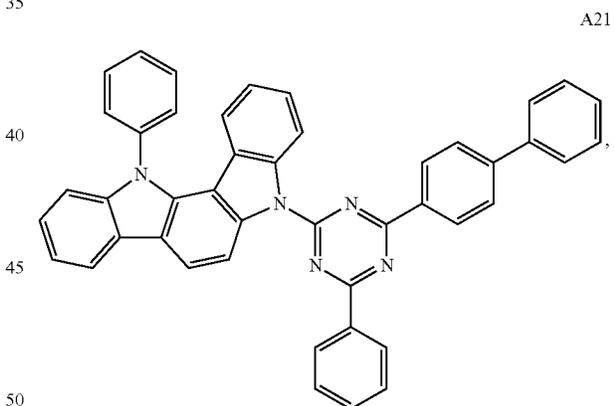
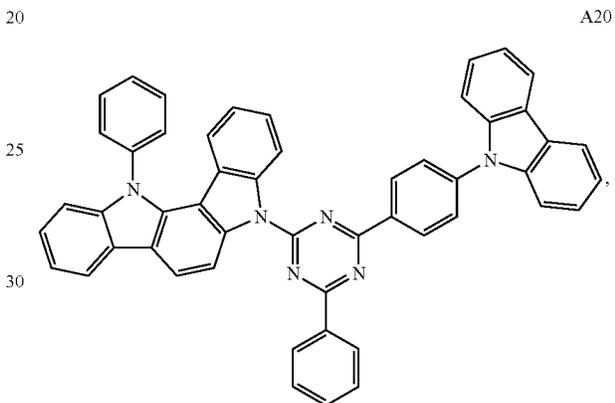
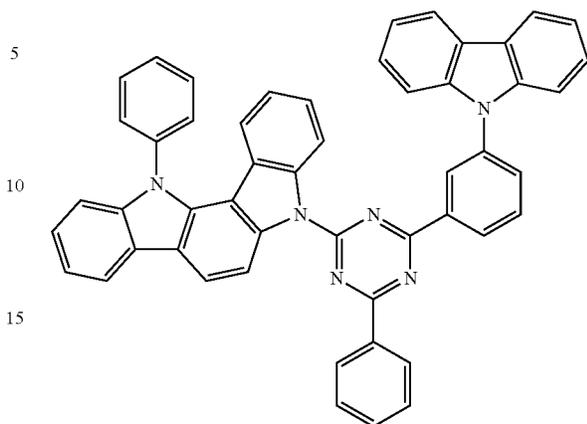
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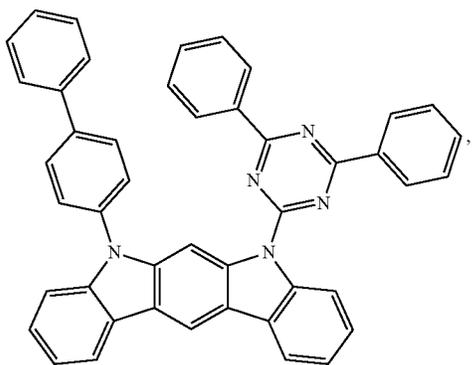


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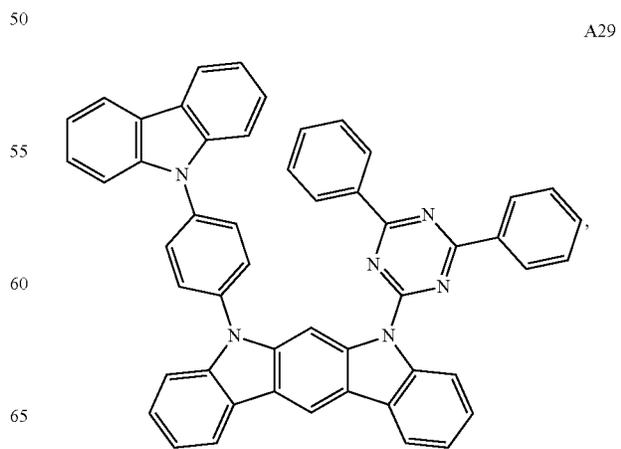
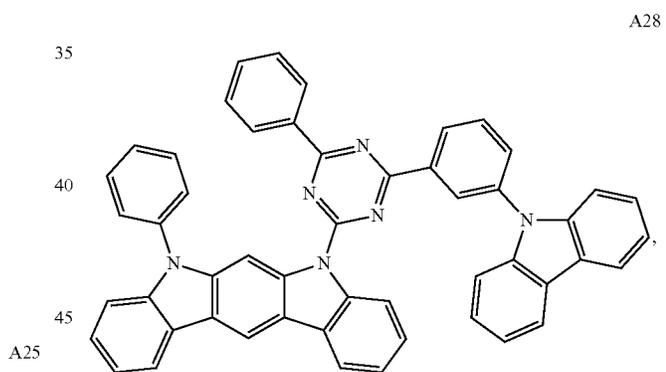
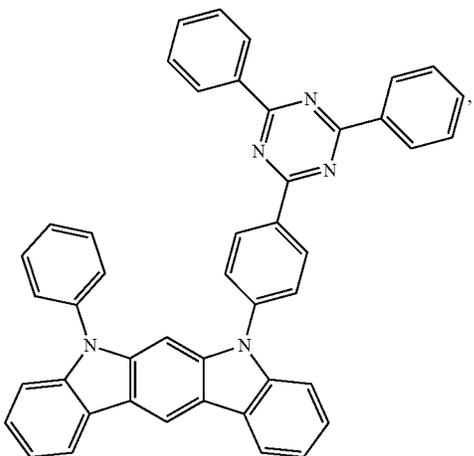
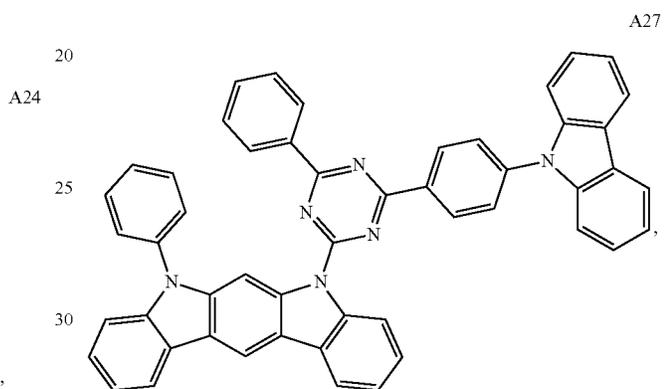
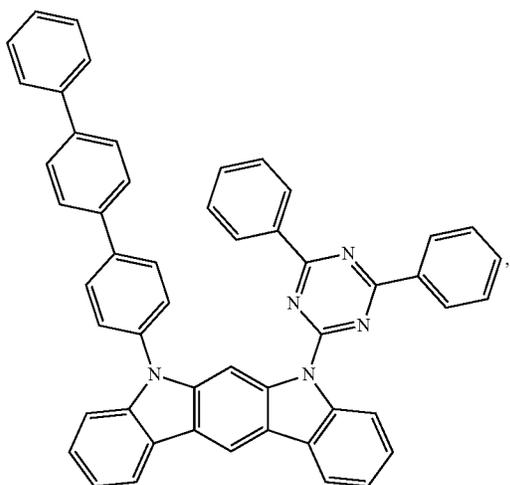
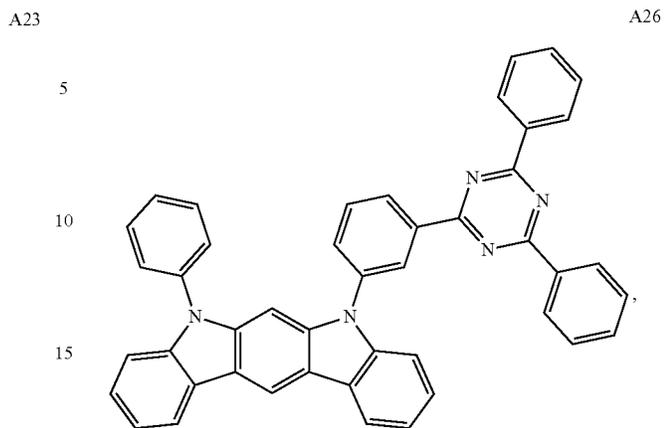
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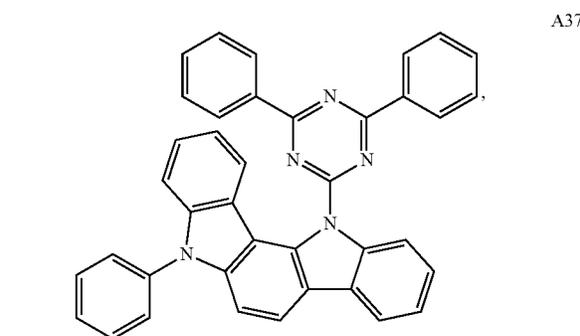
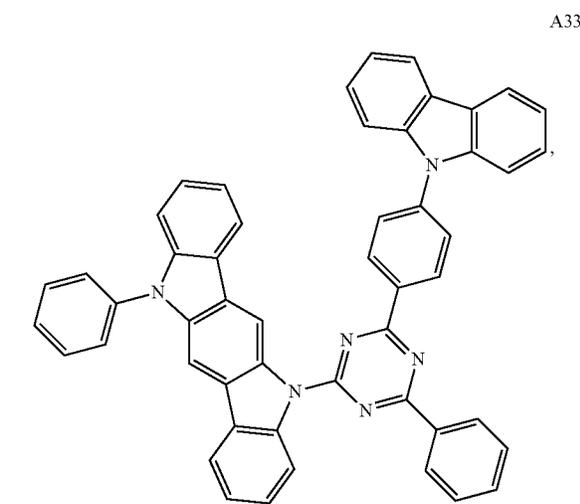
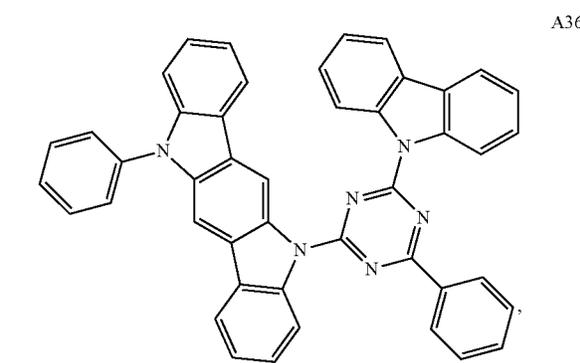
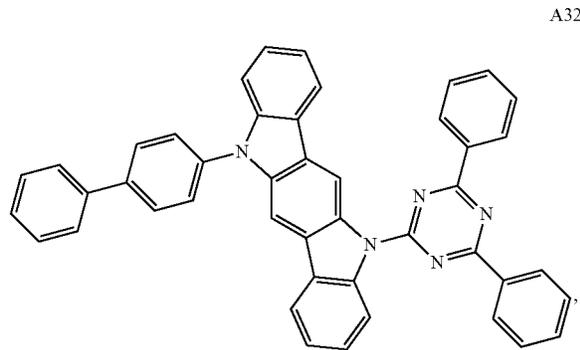
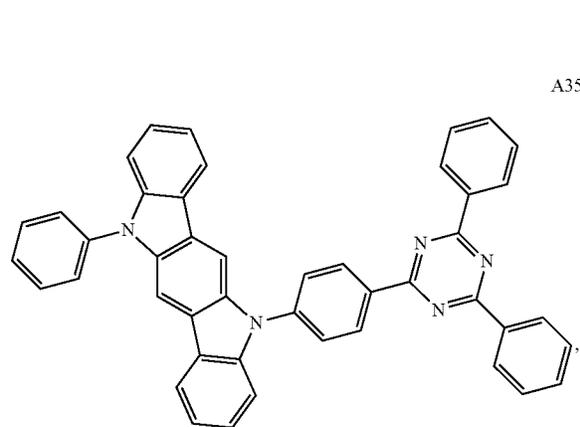
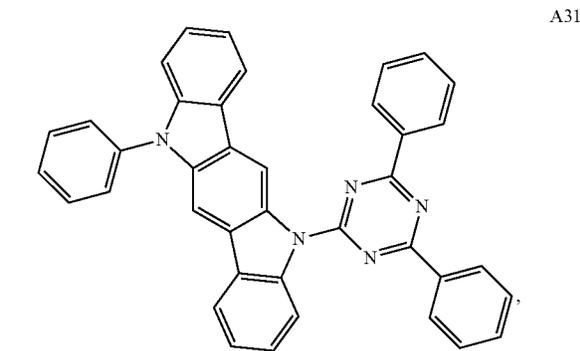
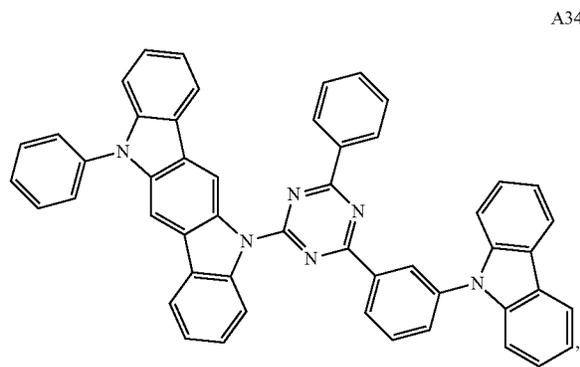
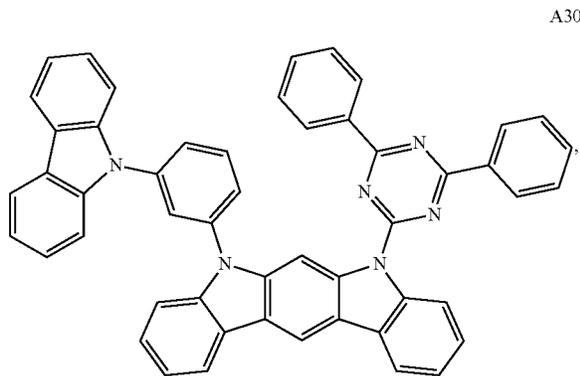


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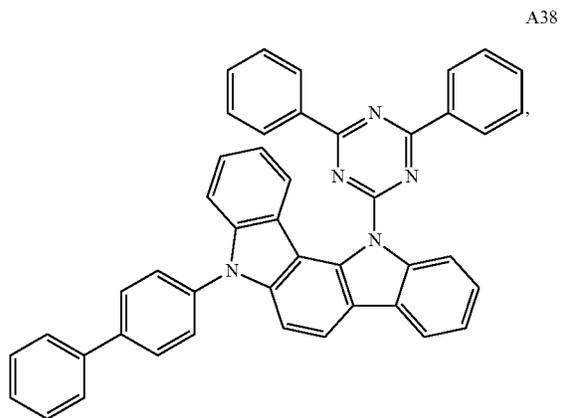


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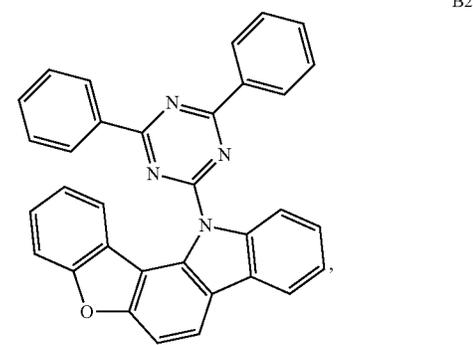
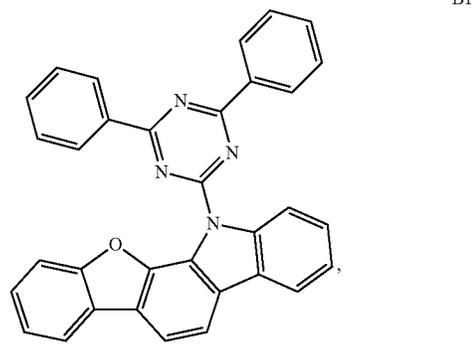
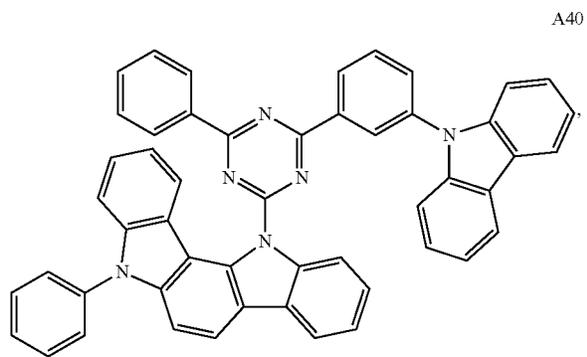
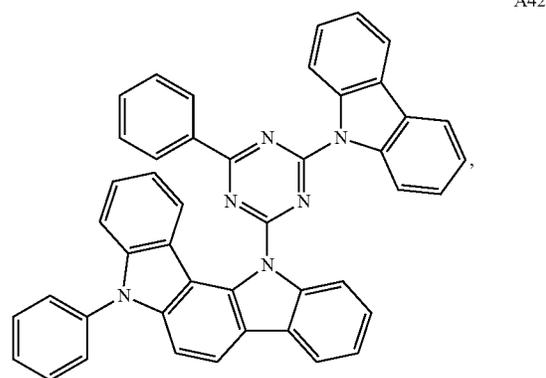
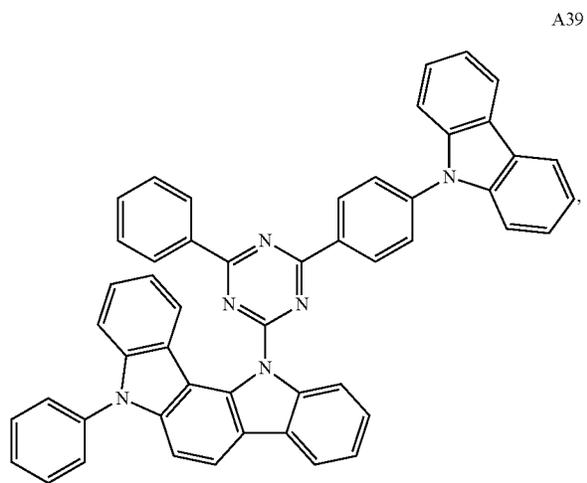
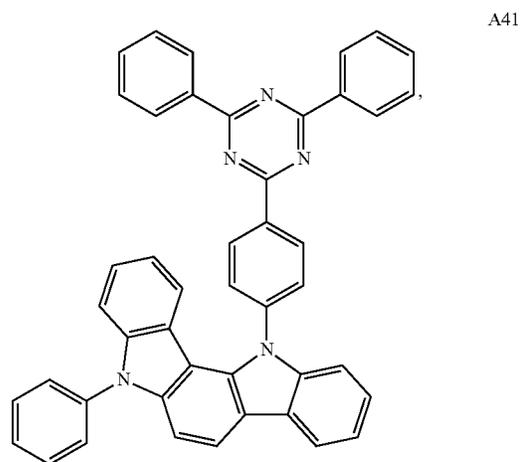
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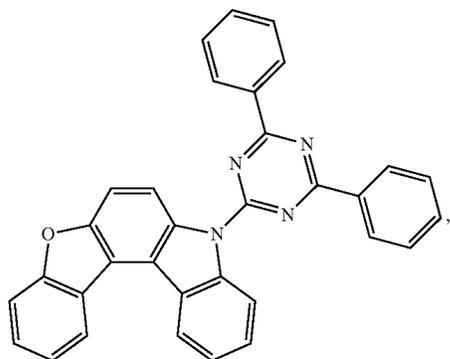
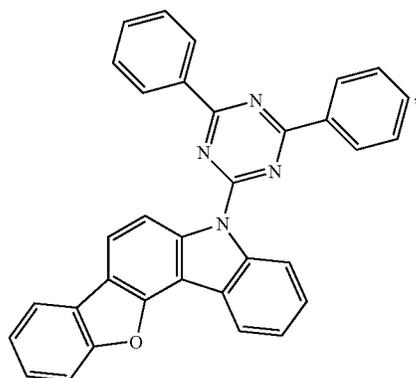
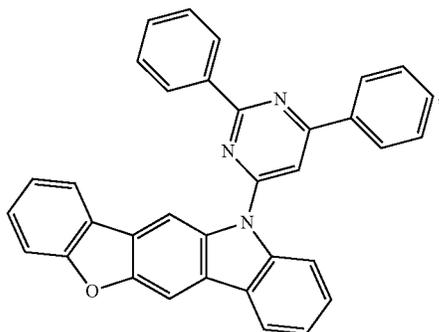
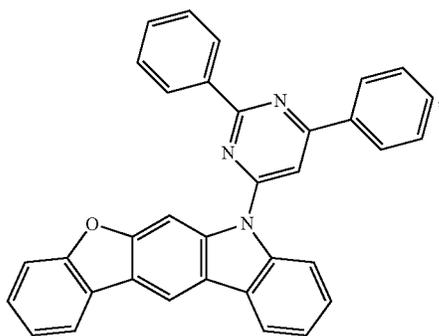


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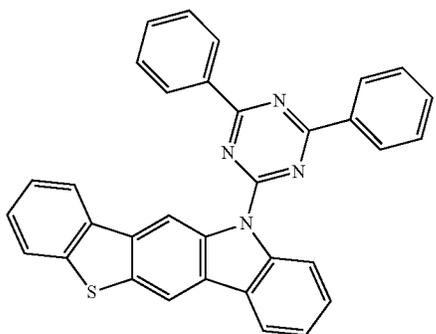
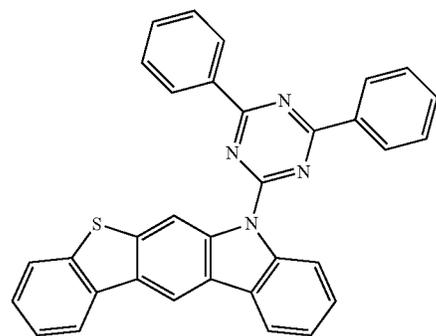
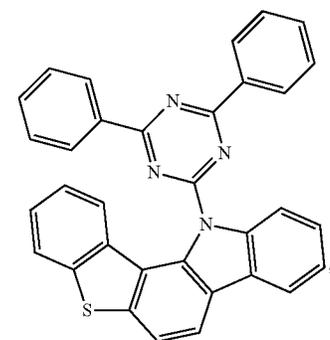
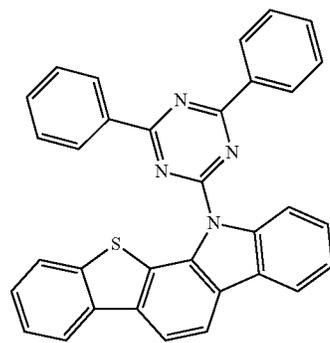
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B7



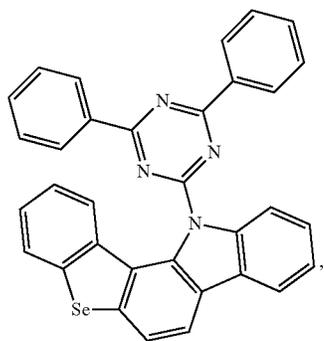
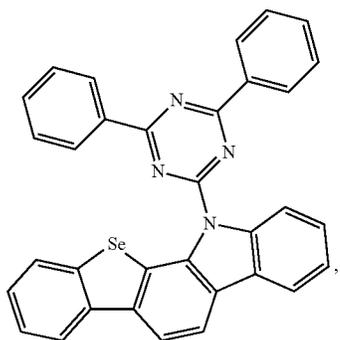
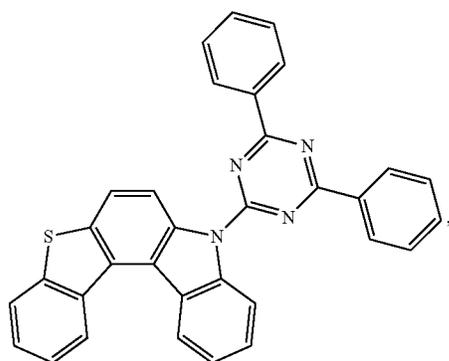
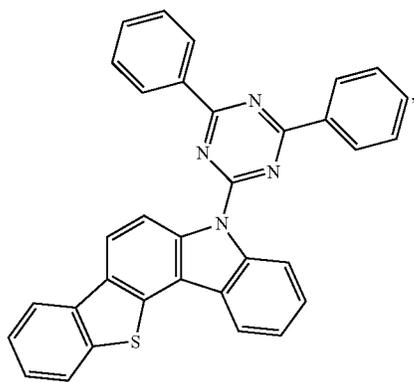
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B9

B10

**35**

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**36**

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B11

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B12

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B13

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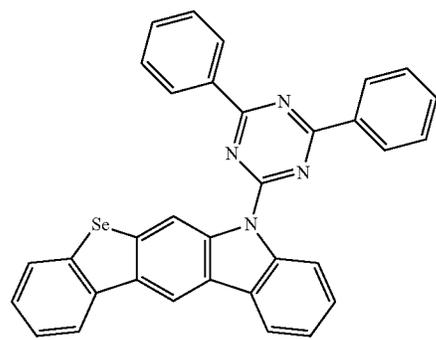
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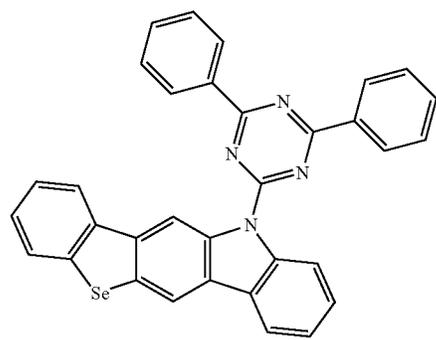
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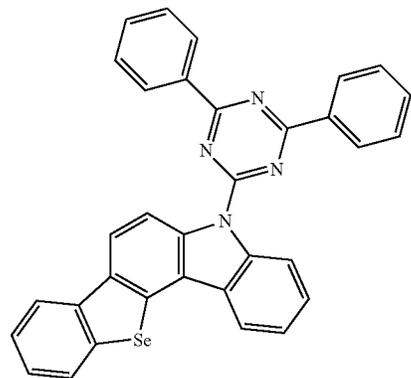
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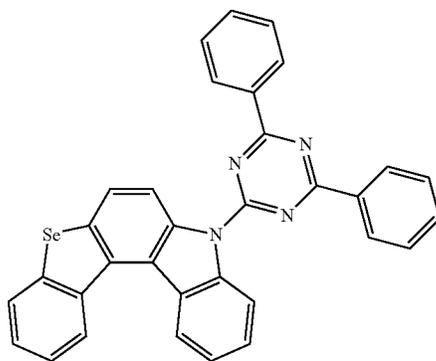
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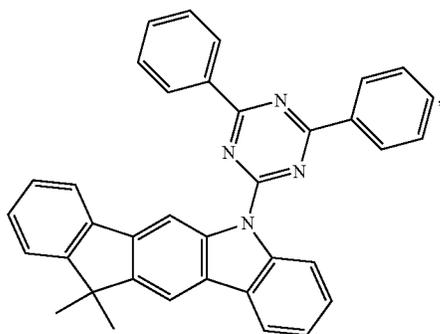
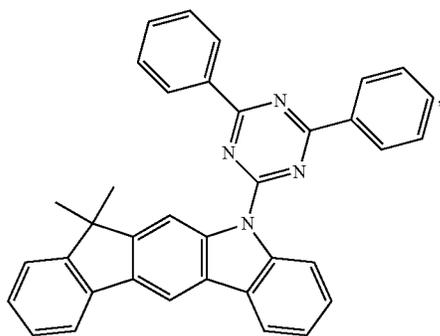
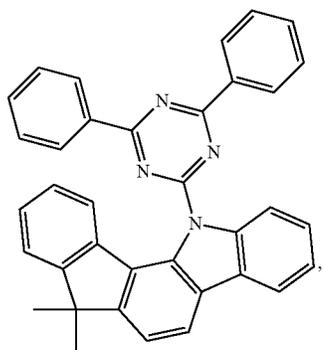
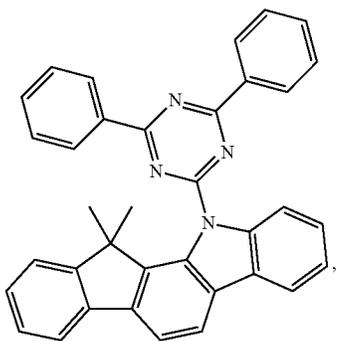
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B18



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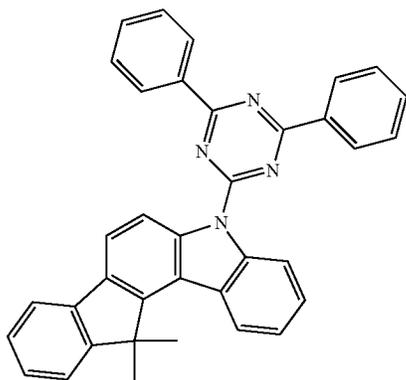
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B19

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B23

B20

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B21

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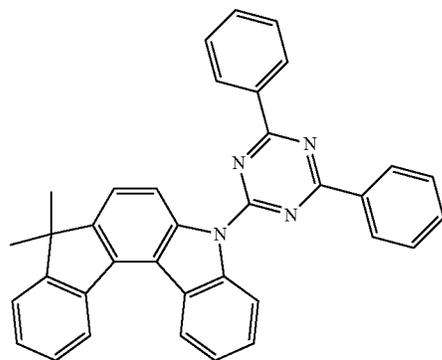
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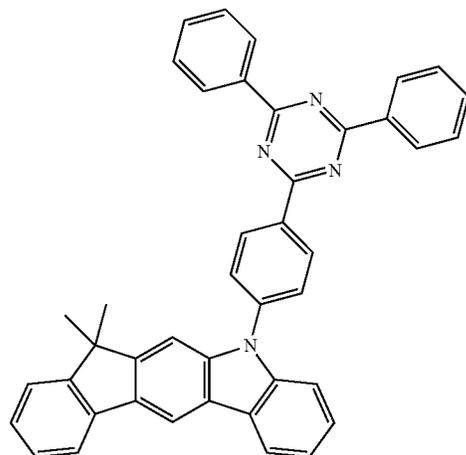
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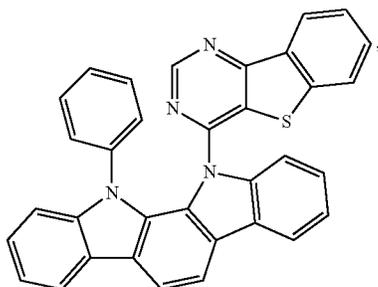
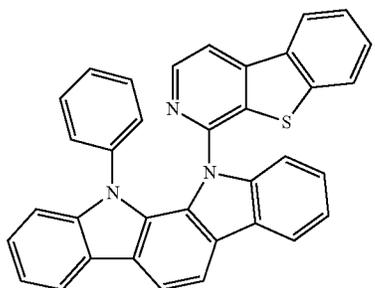
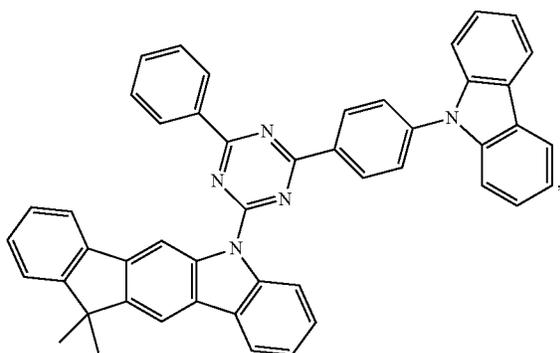
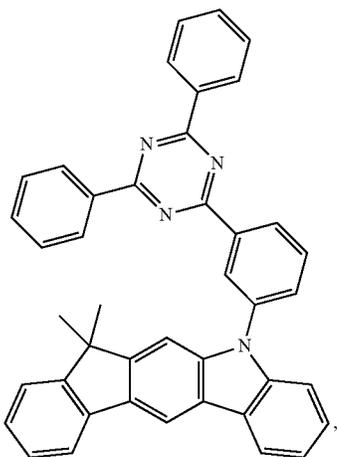
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B25

**39**

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B26

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B27

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C1

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C2

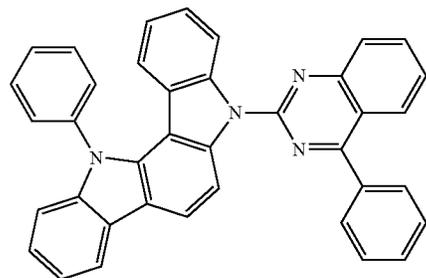
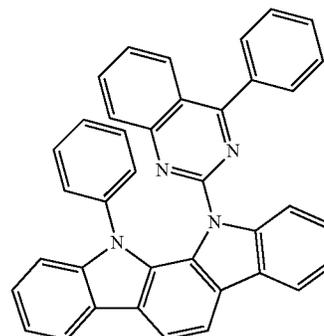
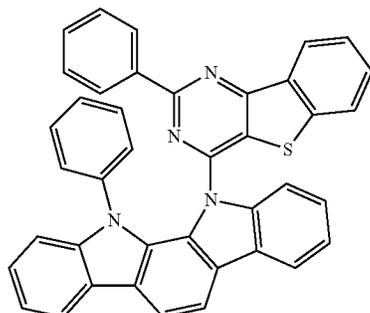
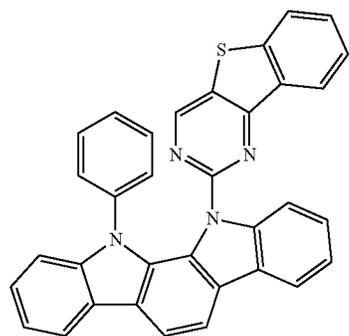
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**40**

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C3

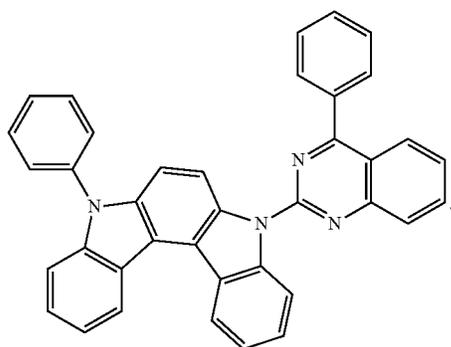
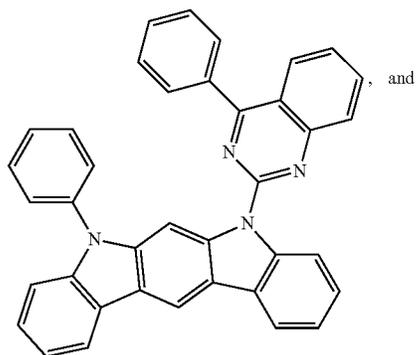
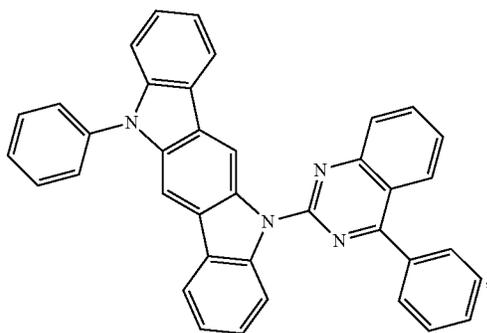
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C5

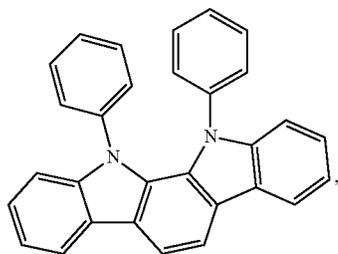
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C7

**41**  
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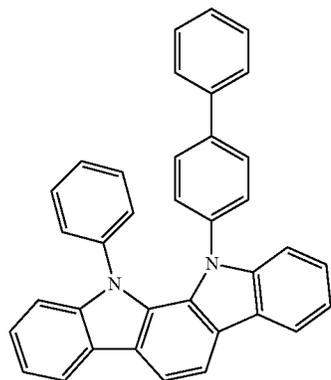


**42**  
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C8

HA2

5



10

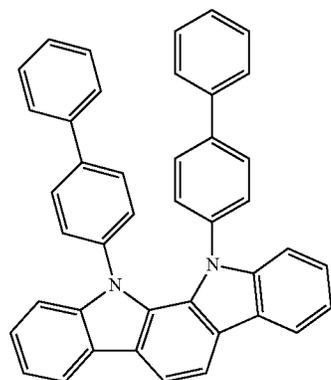
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C9

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HA3

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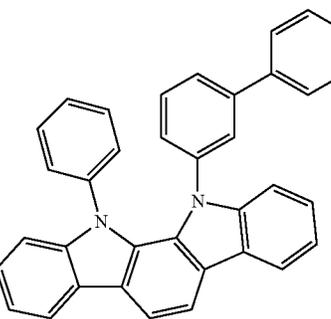
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C10

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HA4

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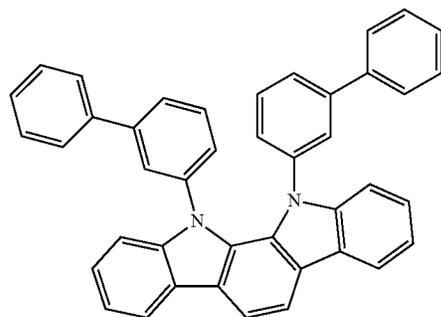
HA1

HA5

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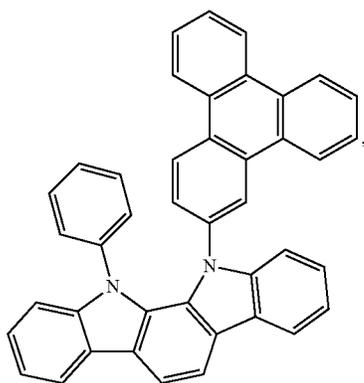
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HA14

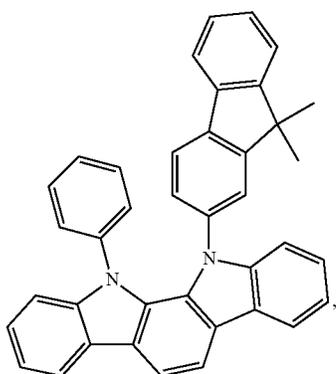
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HA15

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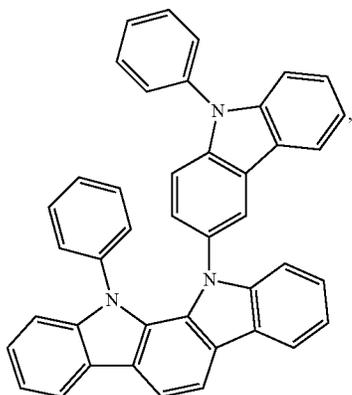


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HA16

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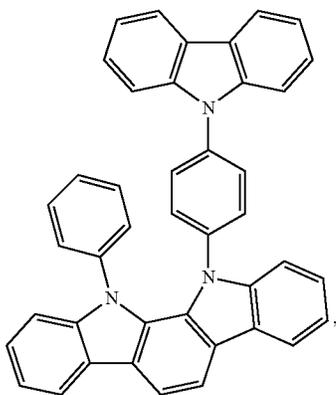
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HA17

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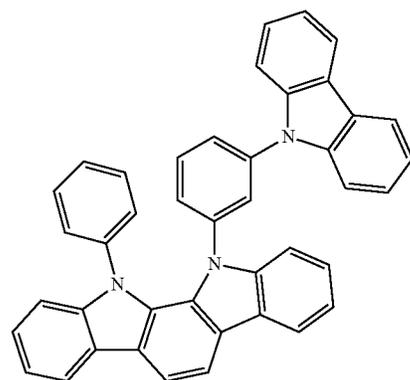
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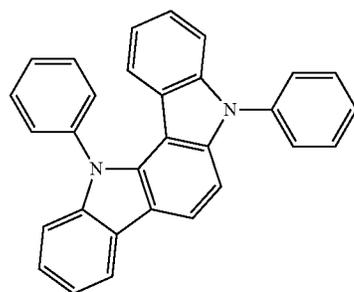


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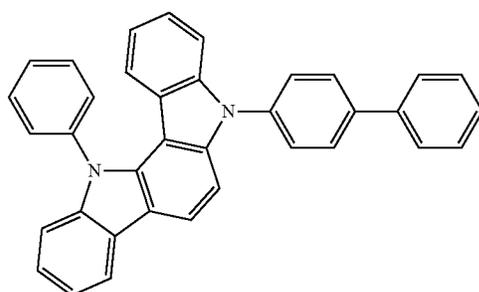
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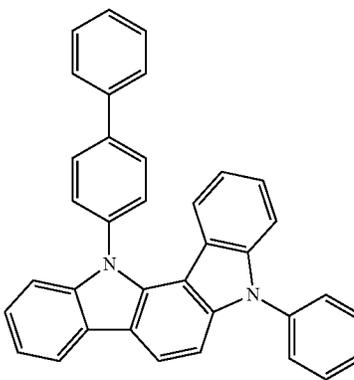
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HA19



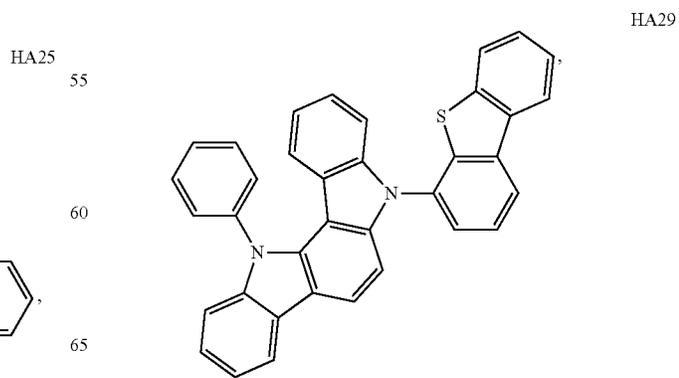
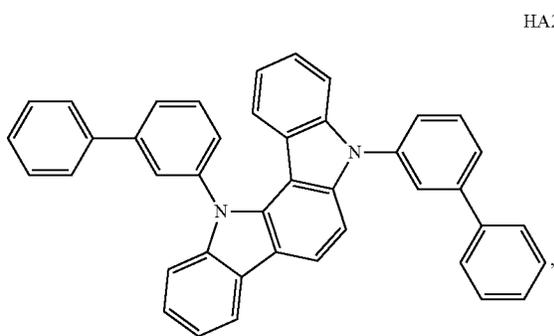
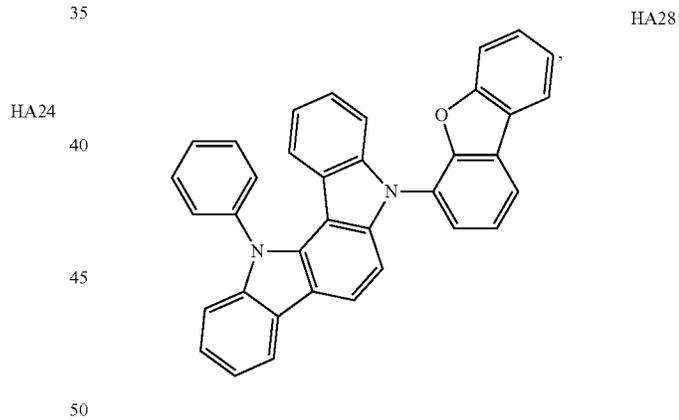
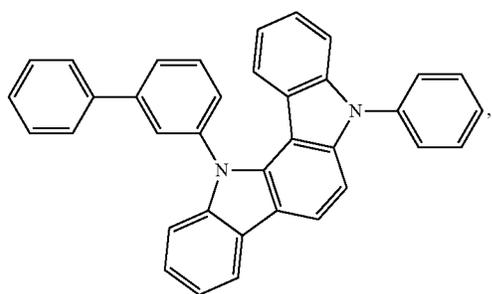
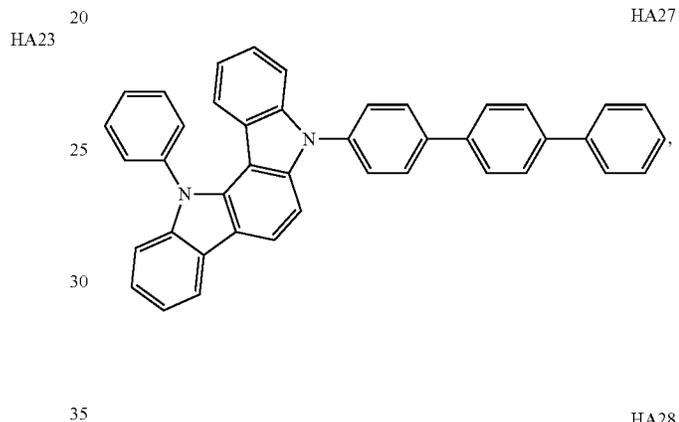
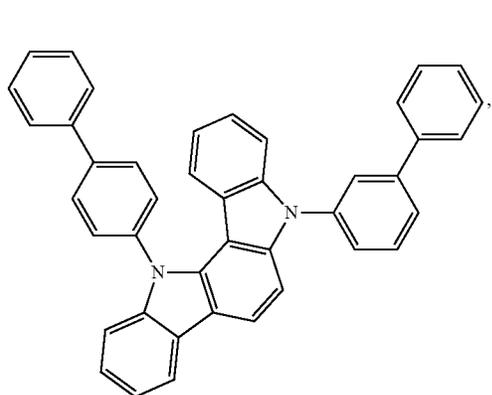
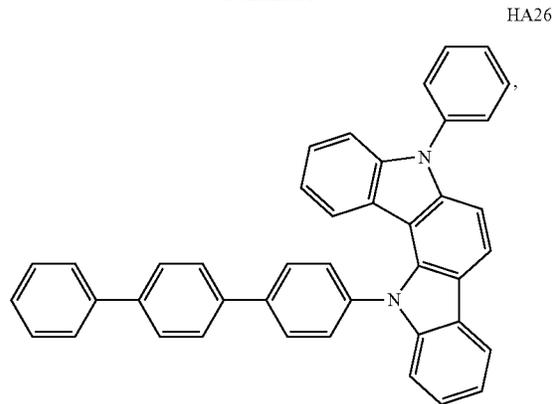
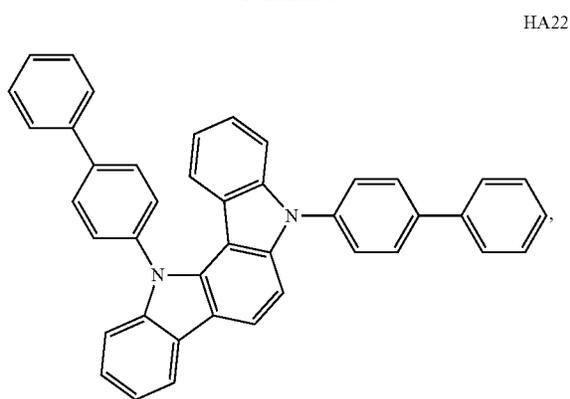
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HA21

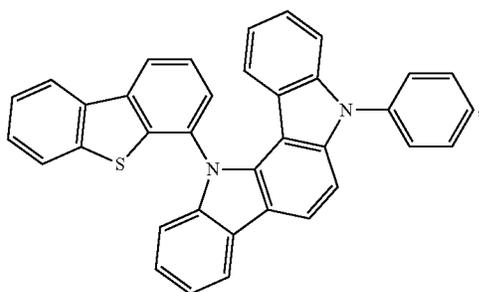
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**48**  
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HA30

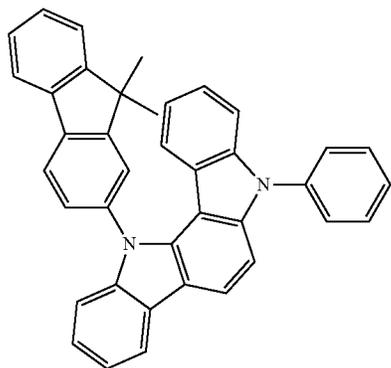
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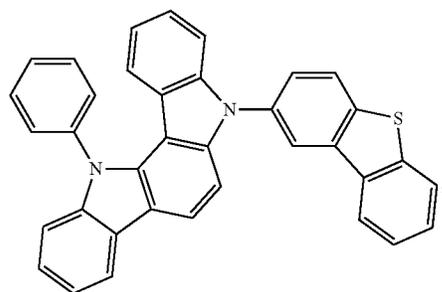
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HA31

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HA35

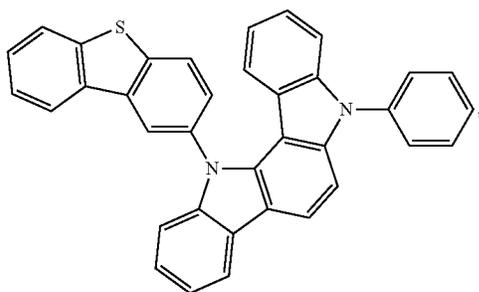
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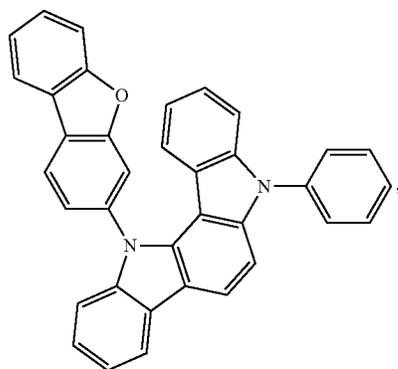
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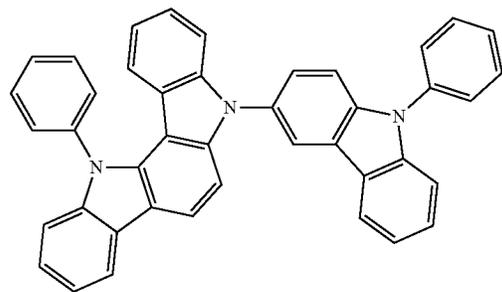
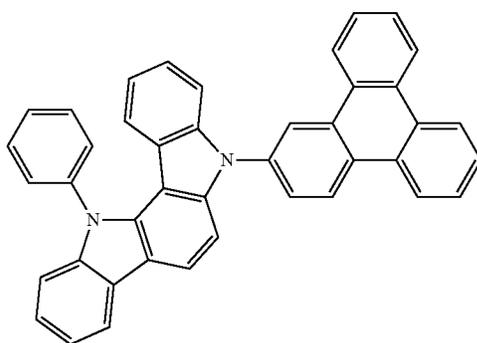
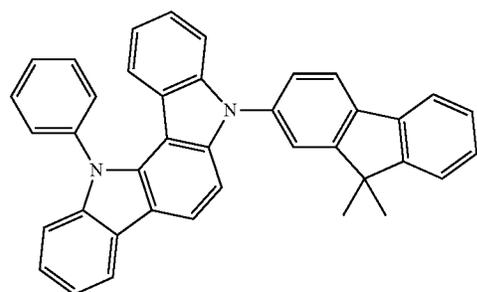
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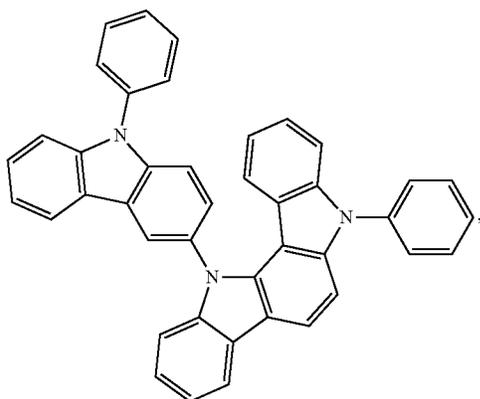


HA37



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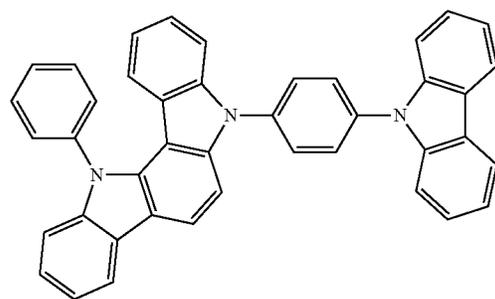
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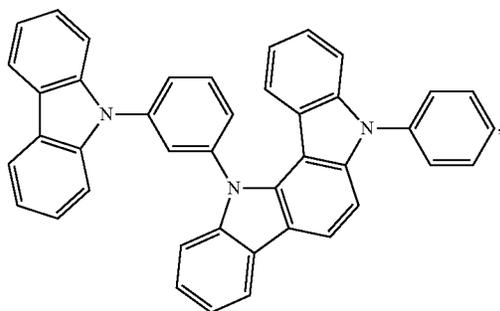


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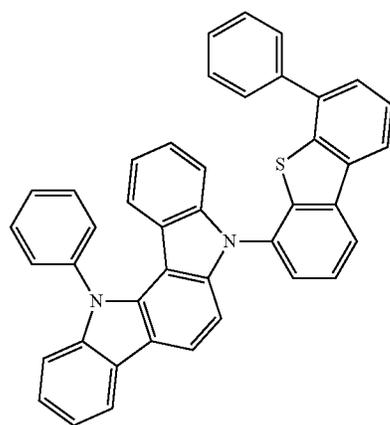
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HA43



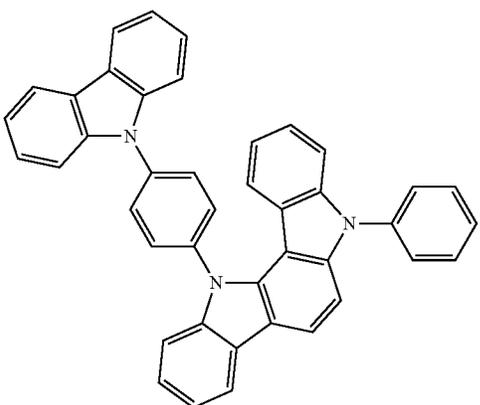
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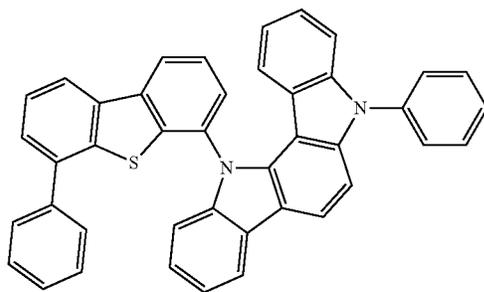
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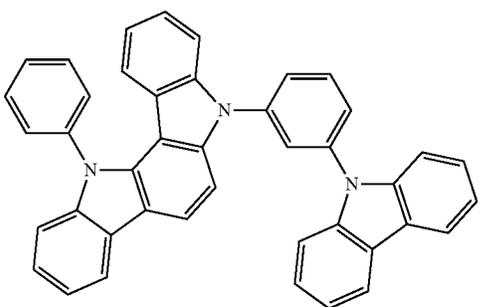


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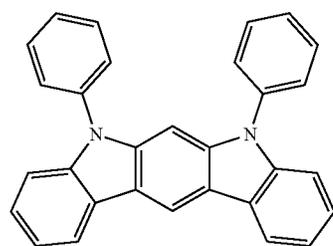
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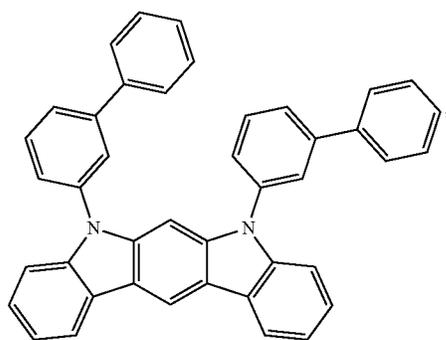
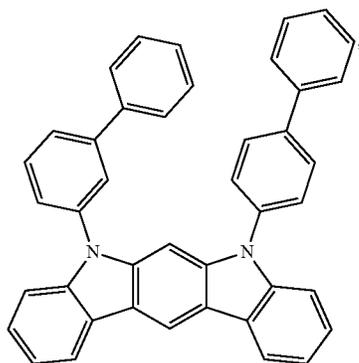
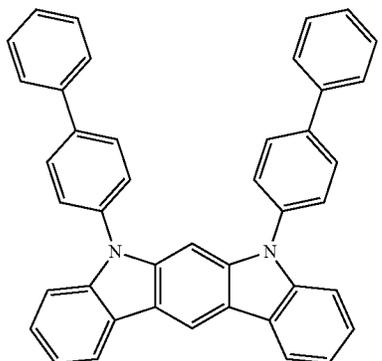
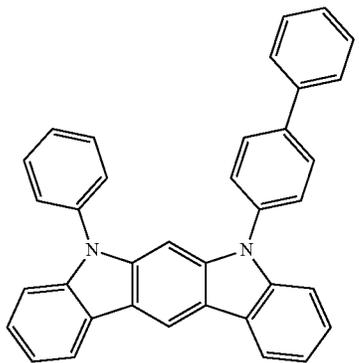


HA45



**53**

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**54**

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HA46

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HA47

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HA48

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HA49

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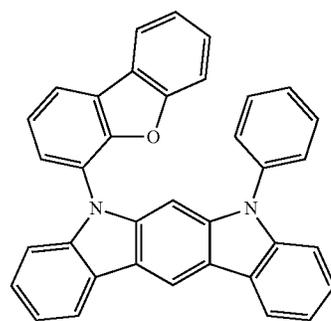
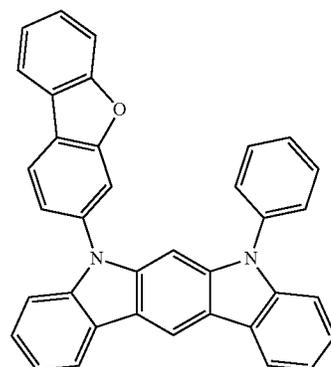
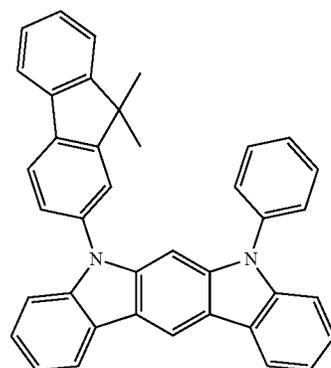
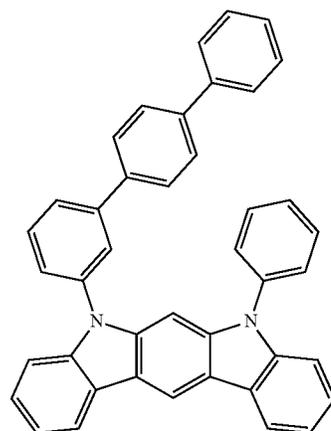
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HA50

HA51

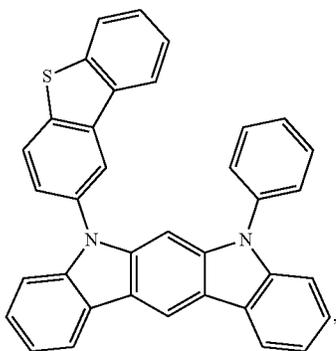
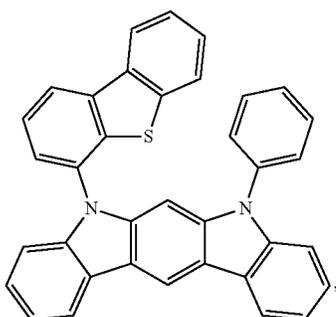
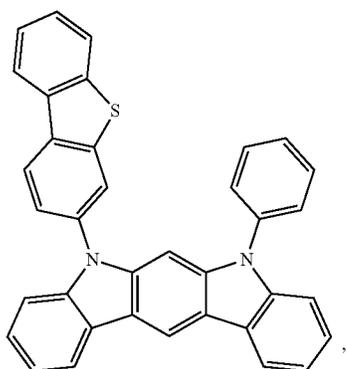
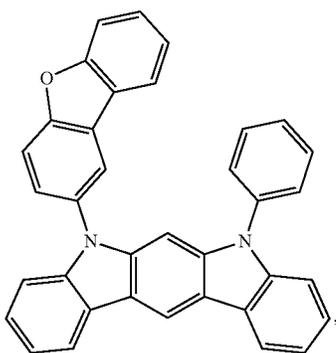
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HA53



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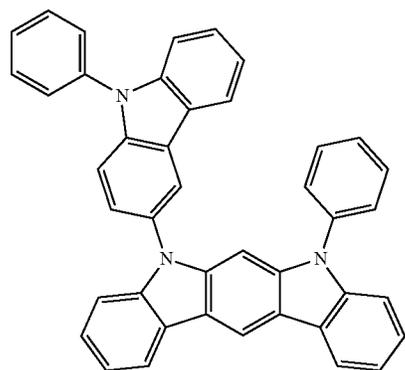


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HA54

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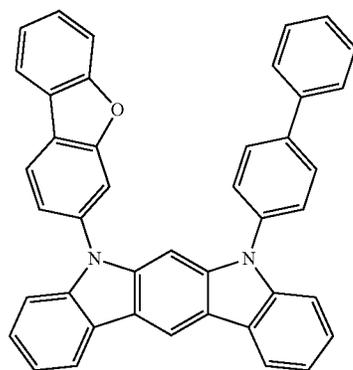
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HA55

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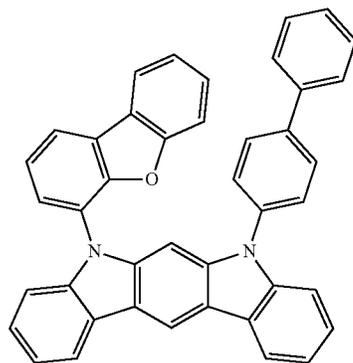
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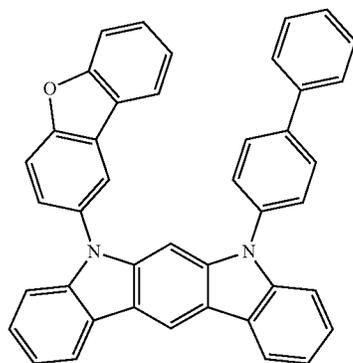


HA57

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HA58

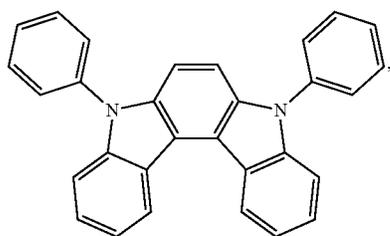
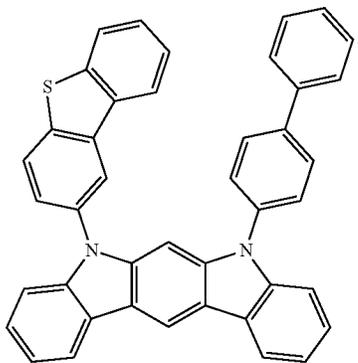
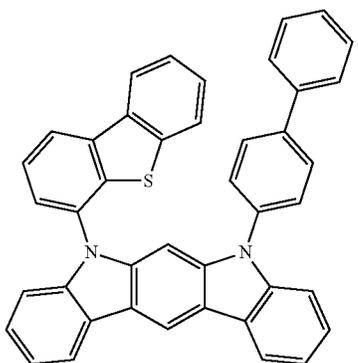
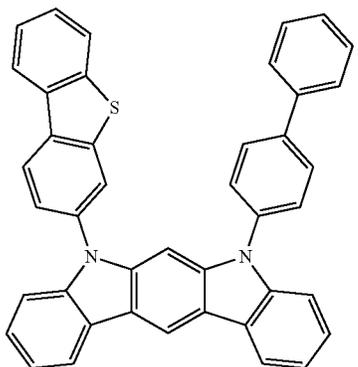
HA59

HA60

HA61

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HA62

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HA63

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HA64

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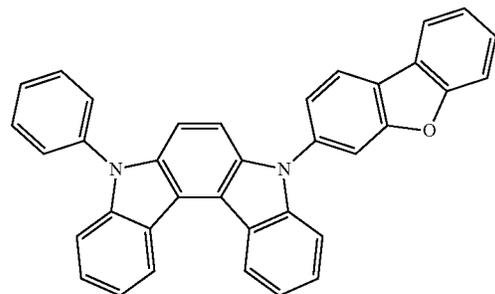
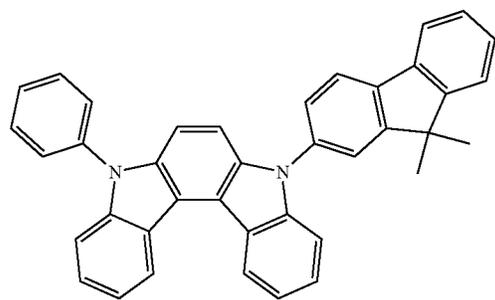
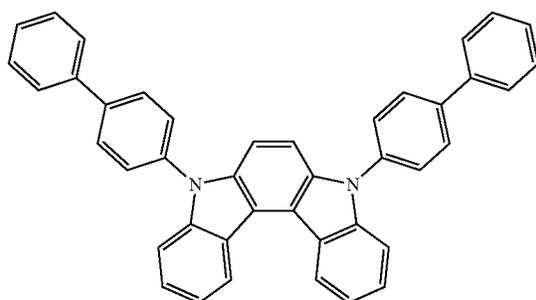
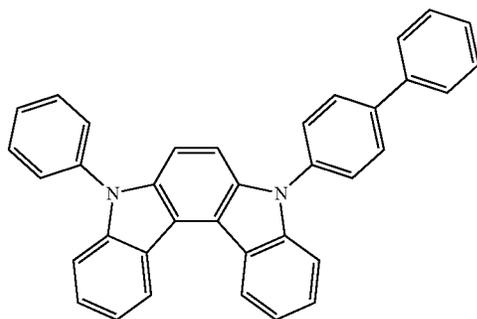
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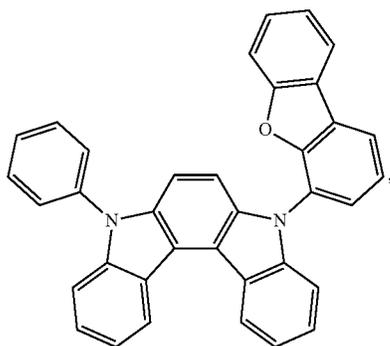
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HA66



**59**

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HA70

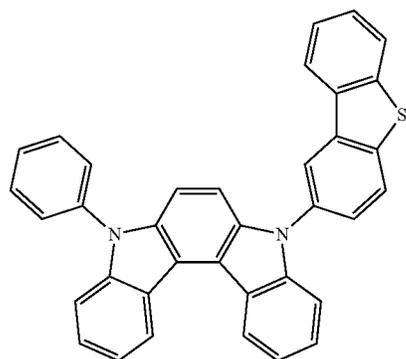
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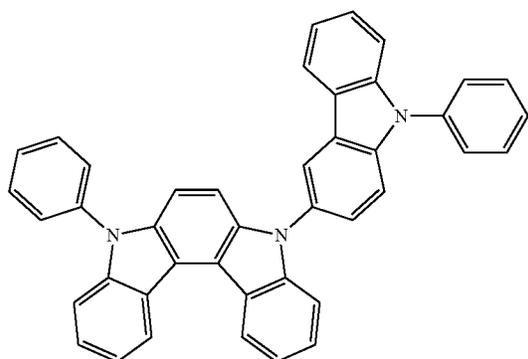
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HA71

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HA75

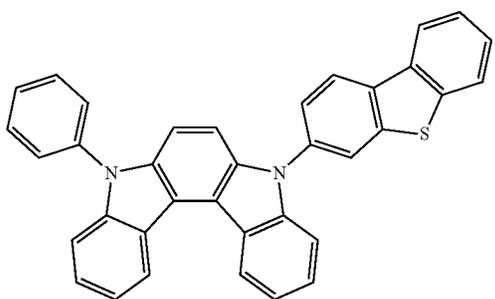
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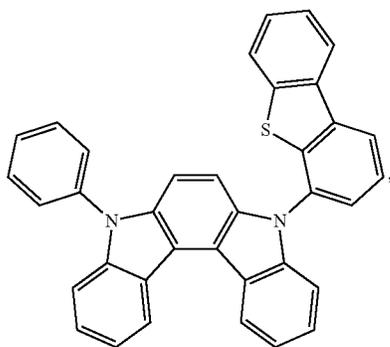
HA76

HA73

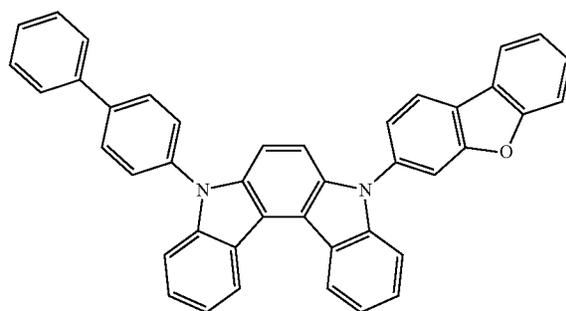
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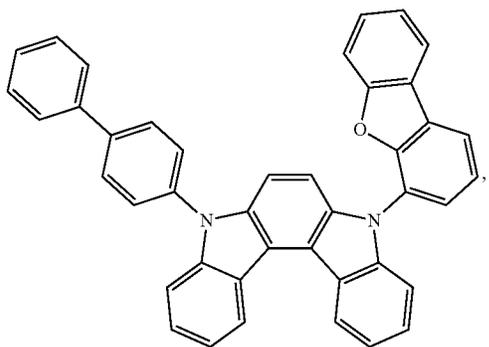


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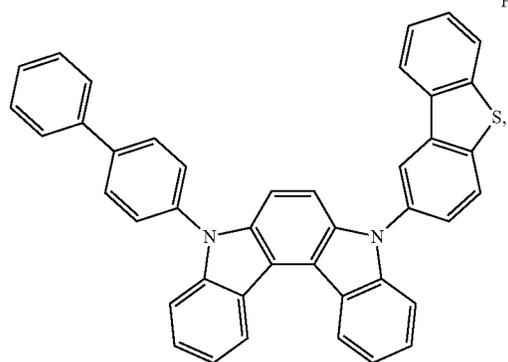
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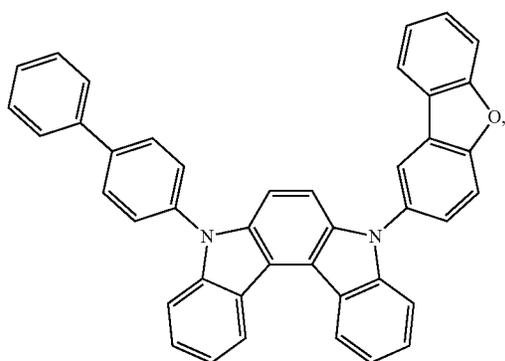


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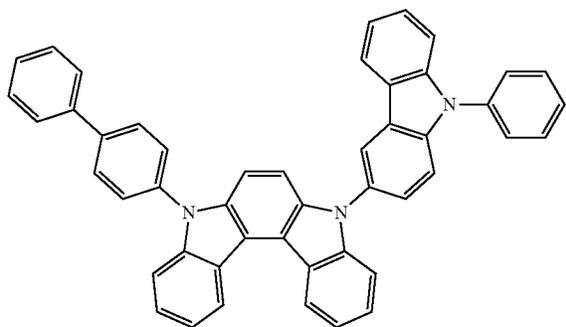


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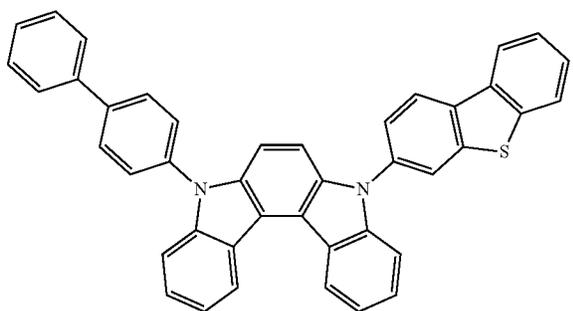


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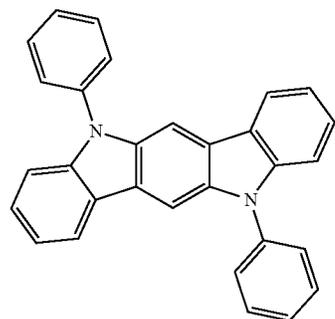
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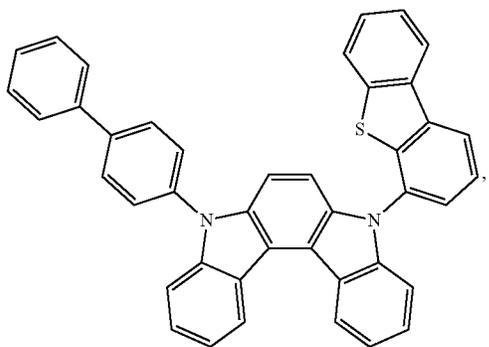


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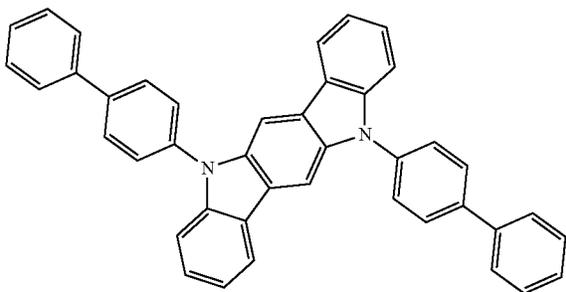
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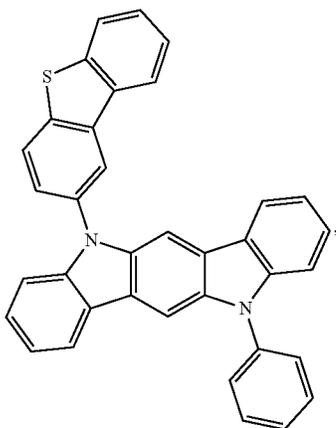
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**63**

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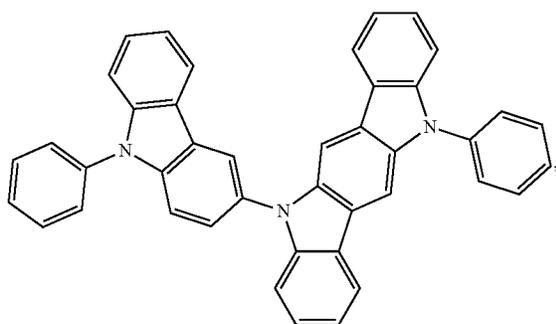
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HA87 20

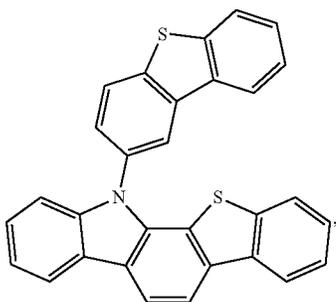


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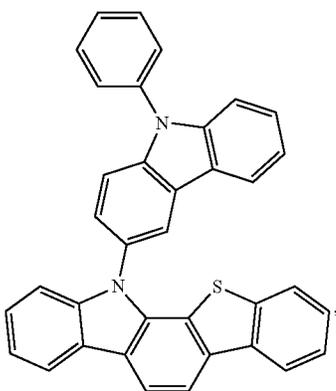
HA88



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HA89



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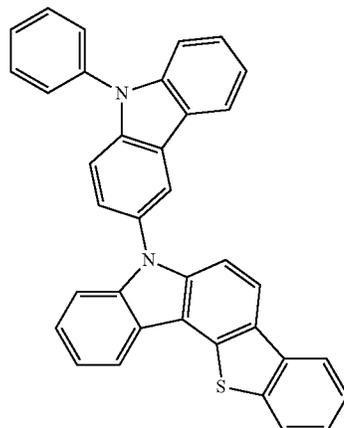
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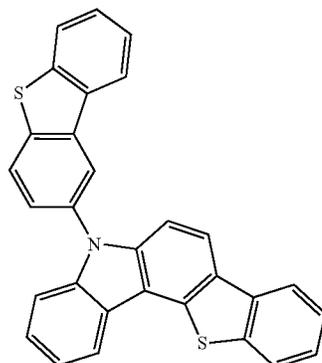
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HA87 20

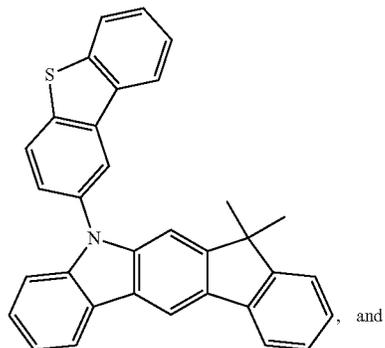


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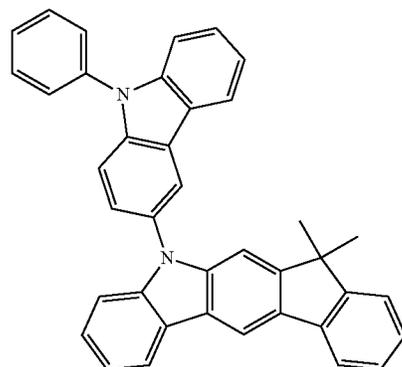
HA88



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HA89



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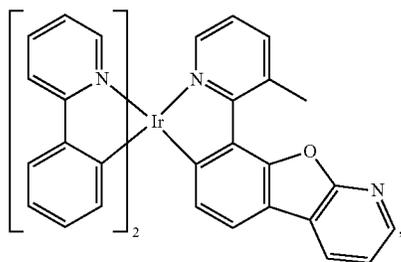
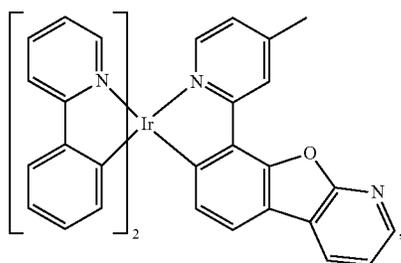
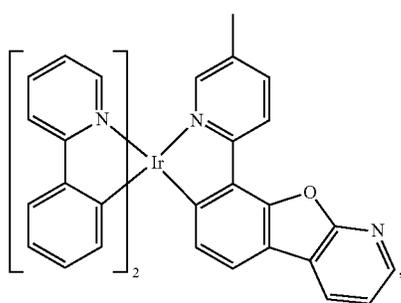
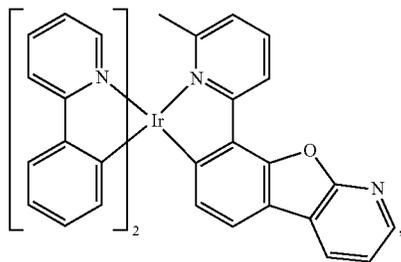
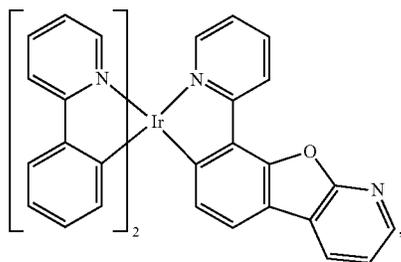
HA91

HA92

HA93

In some embodiments of the composition of material, the second compound is selected from the group consisting of:

**65**

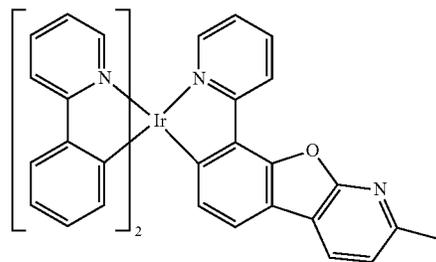


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D1

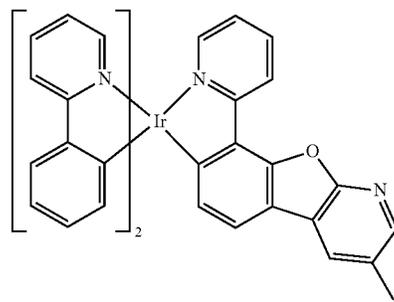
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D2

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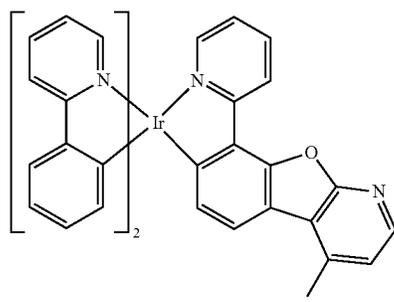


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D3

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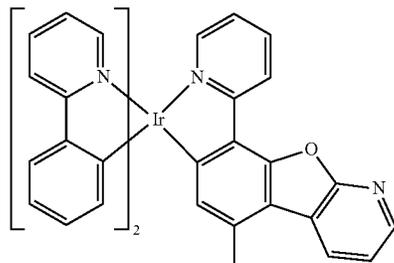


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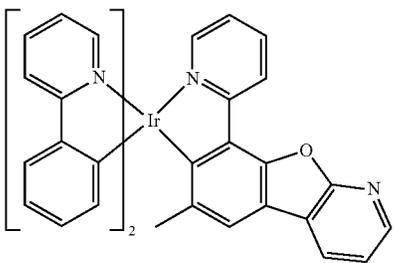
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D5

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D6

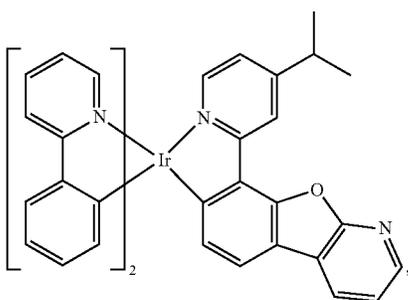
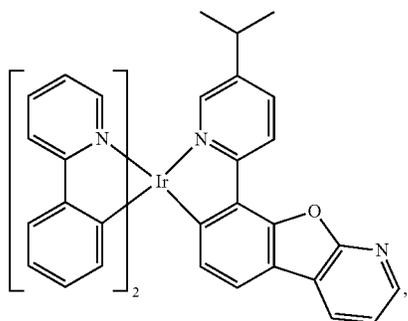
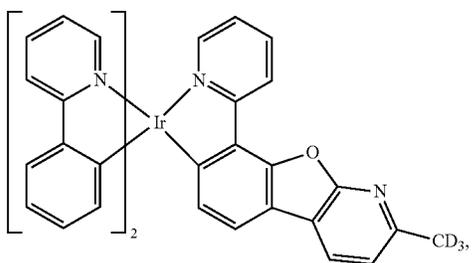
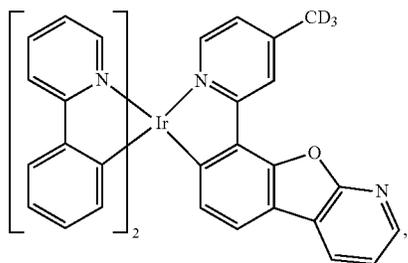
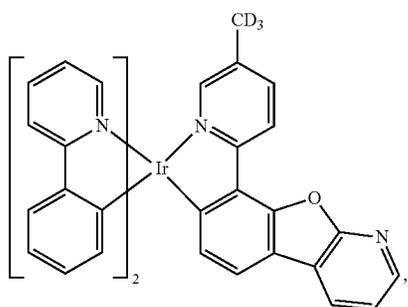
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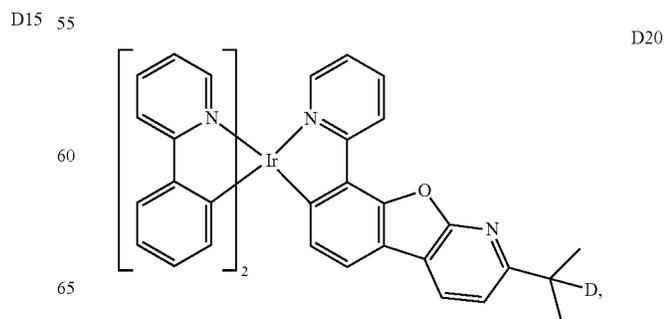
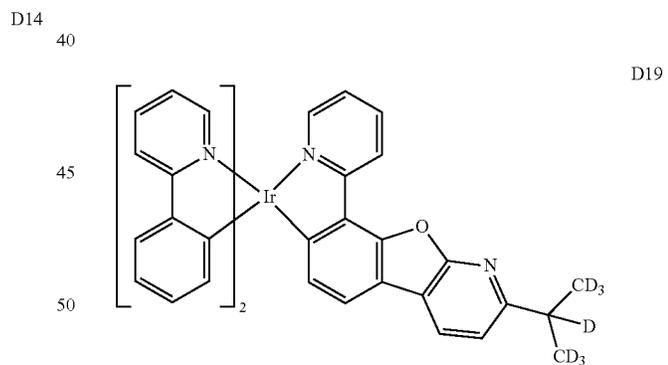
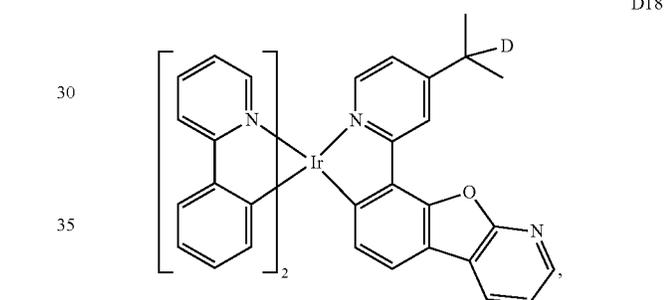
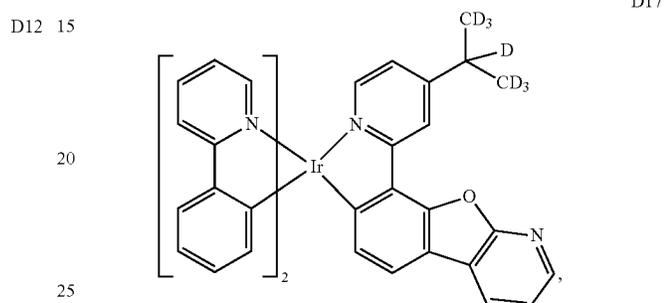
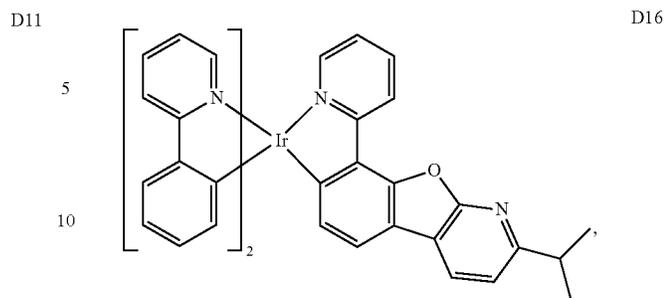
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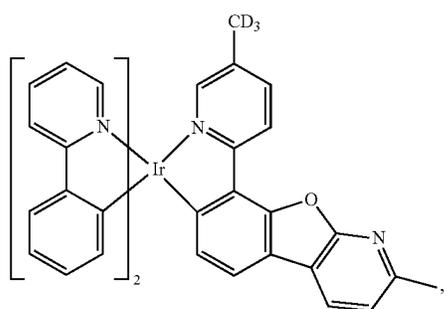
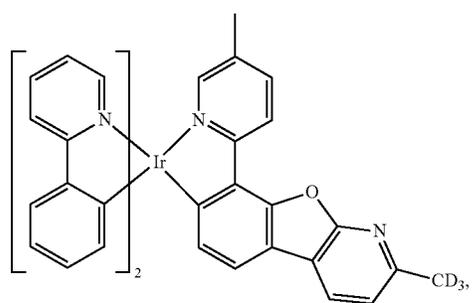
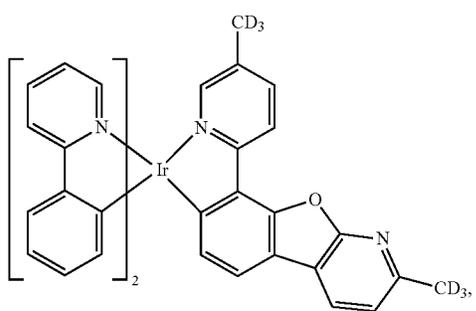
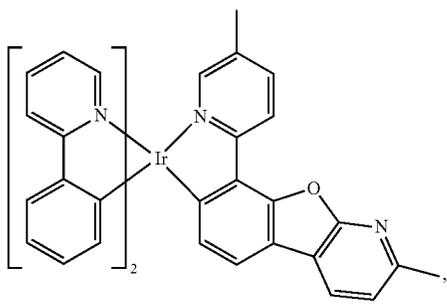
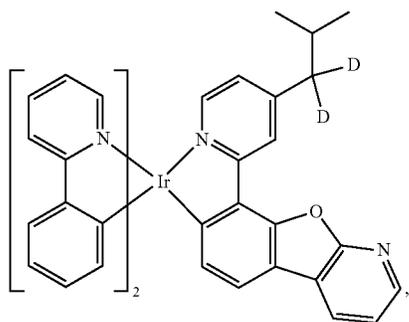


**68**  
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**69**

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**70**

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D21

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D22 15

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D23

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D24 40

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D25 55

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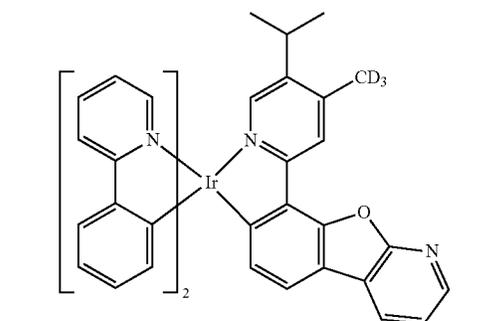
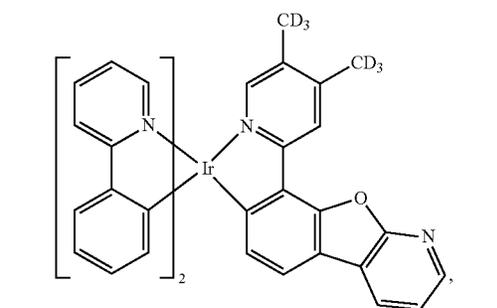
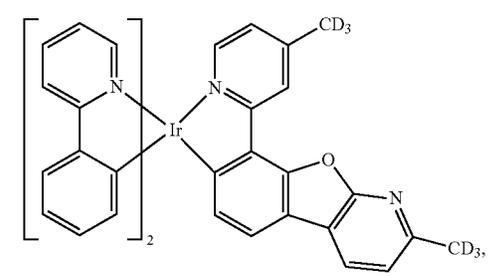
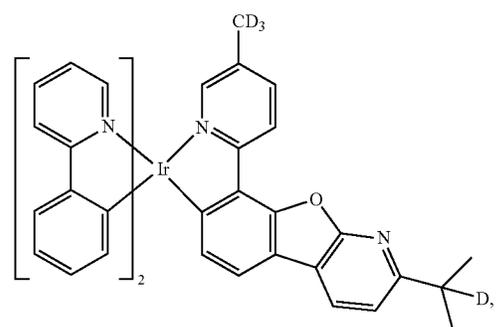
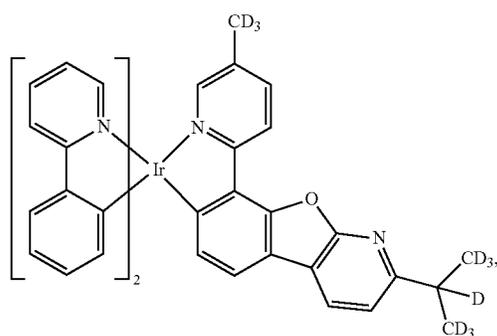
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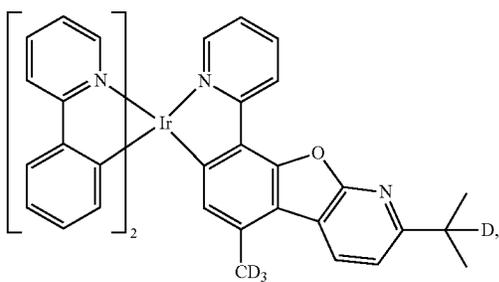
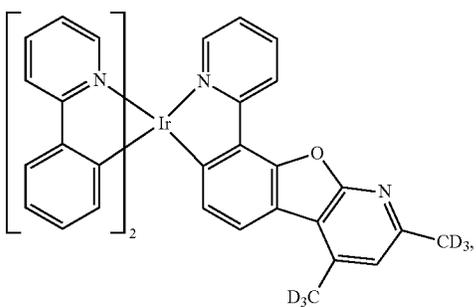
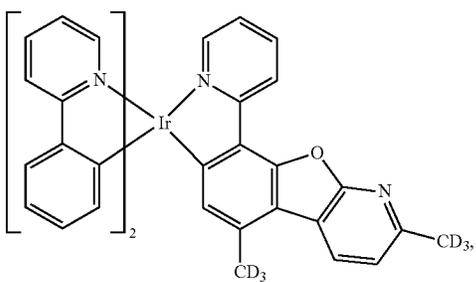
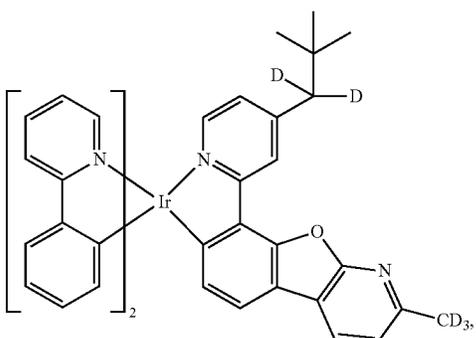
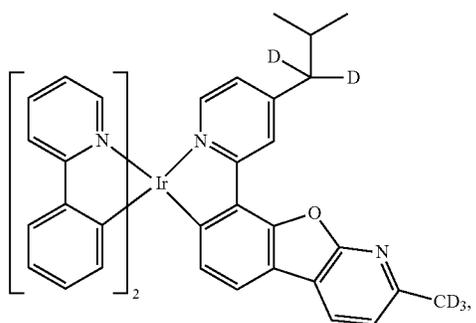
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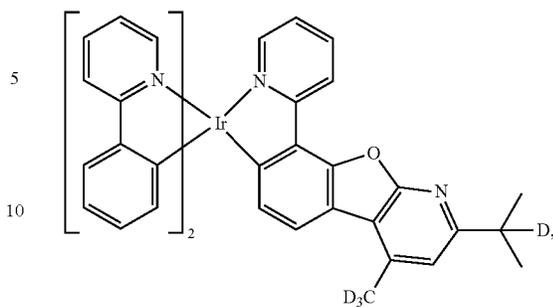


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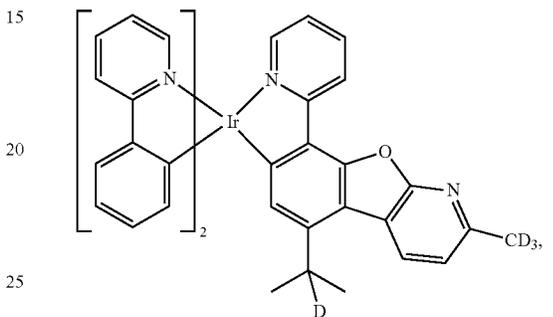
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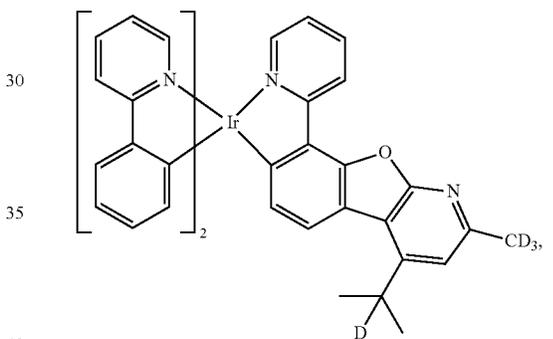
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D32



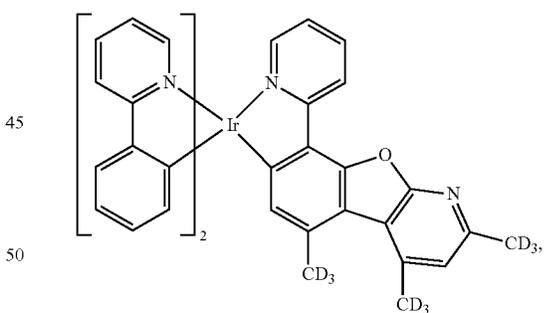
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D33



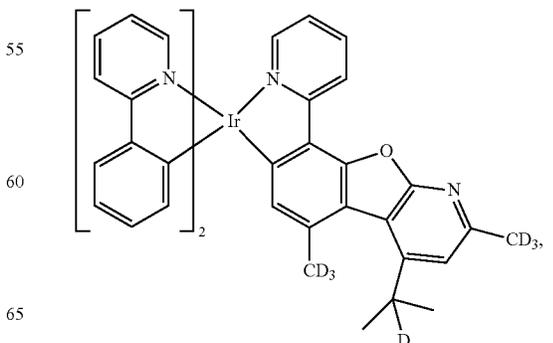
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D35



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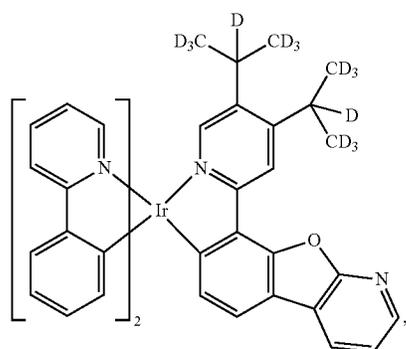
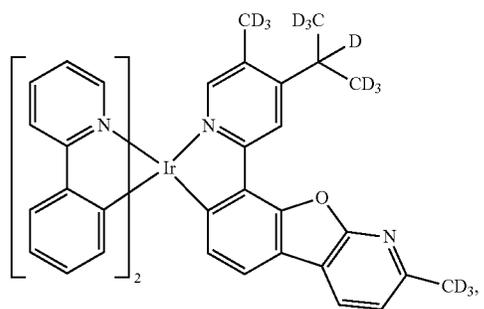
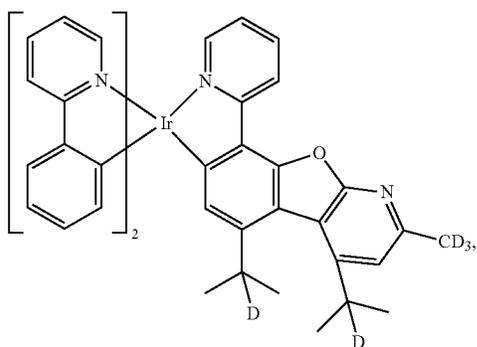
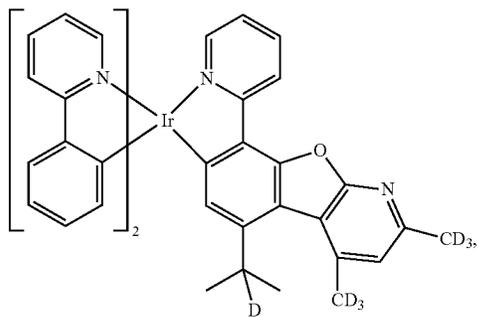
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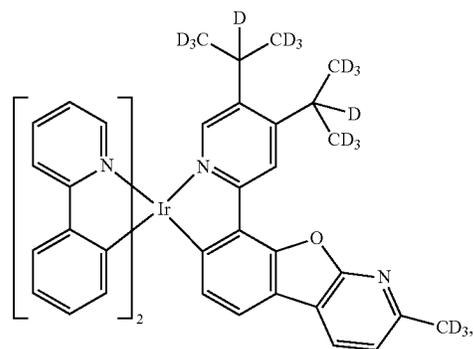
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D45

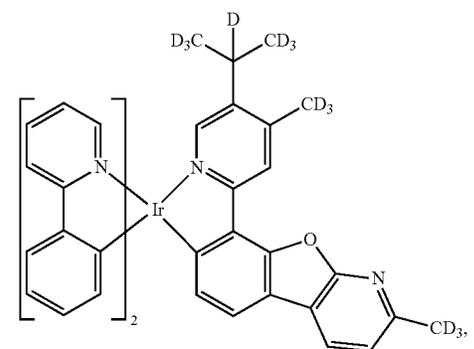
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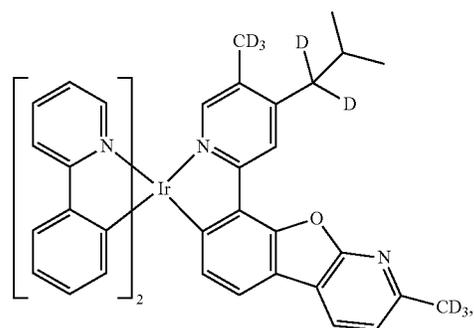
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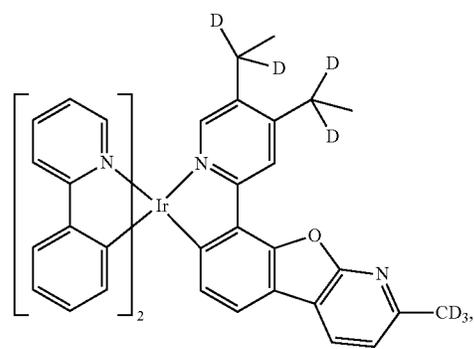
D47

D44

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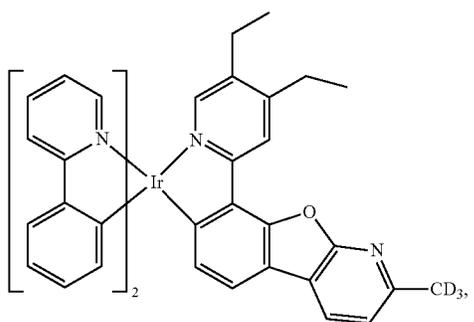
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D48

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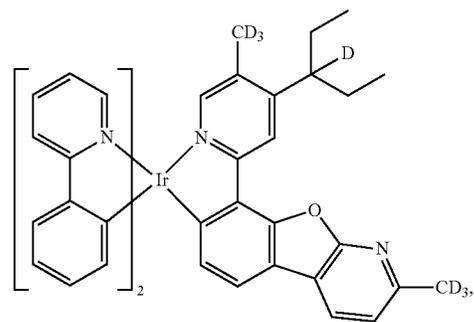
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D53

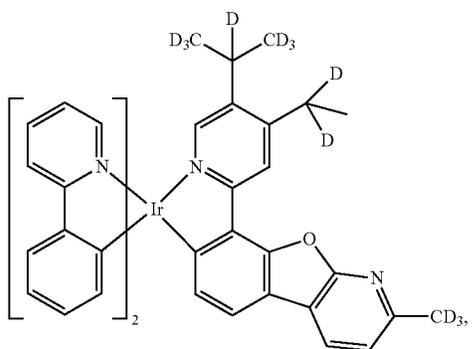
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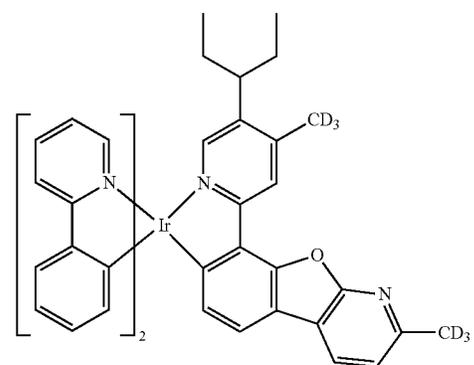


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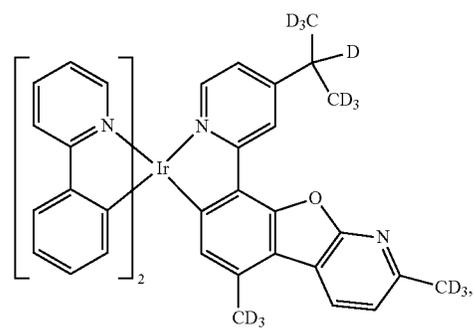
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D54



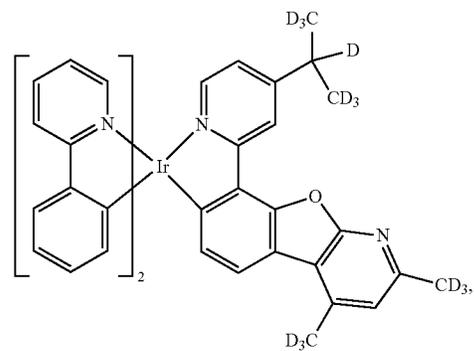
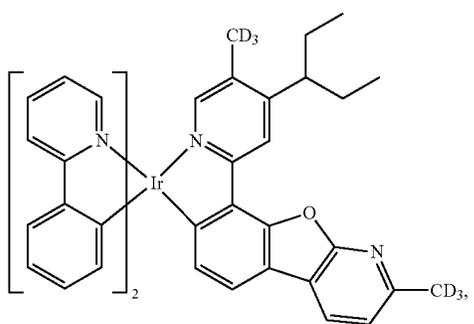
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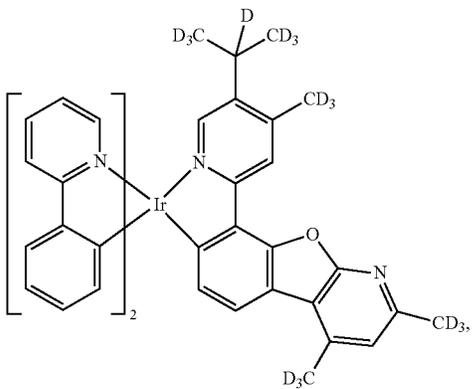
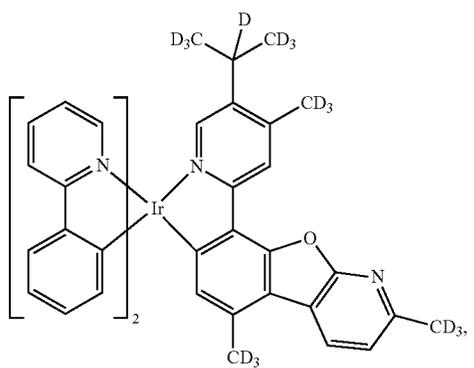
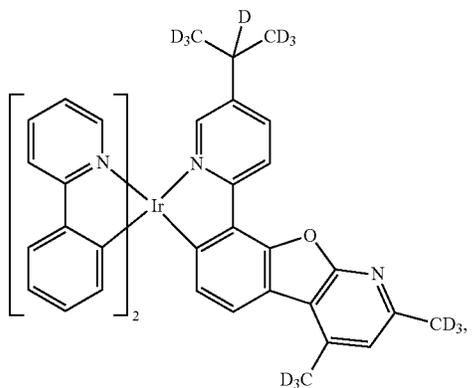
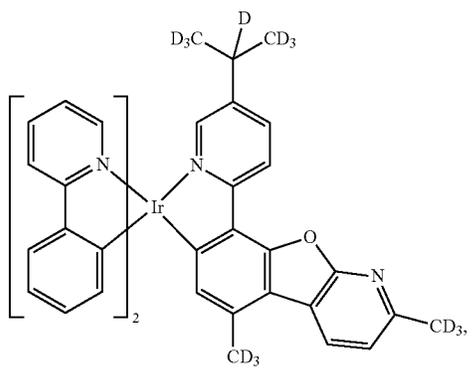
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D56

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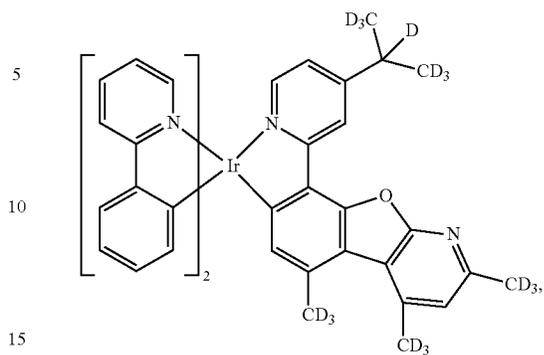
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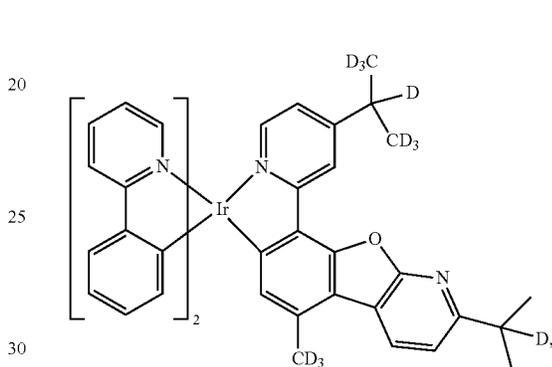
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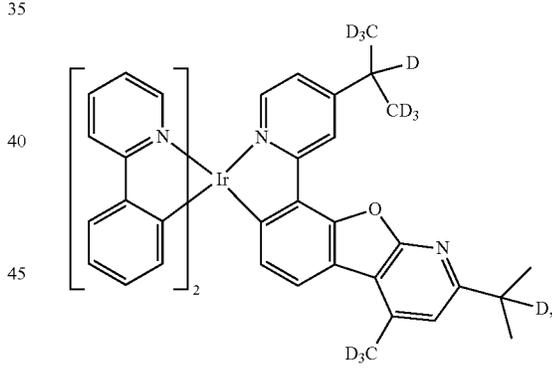
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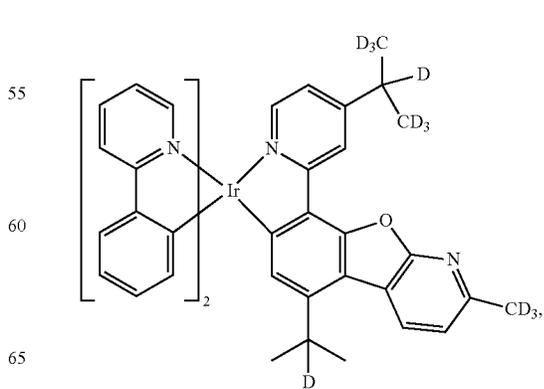
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D59



D63

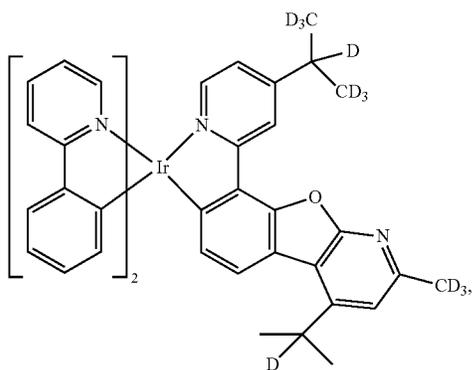
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D64

**79**

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D65

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D67

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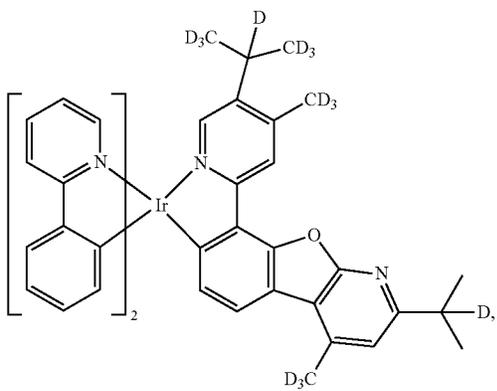
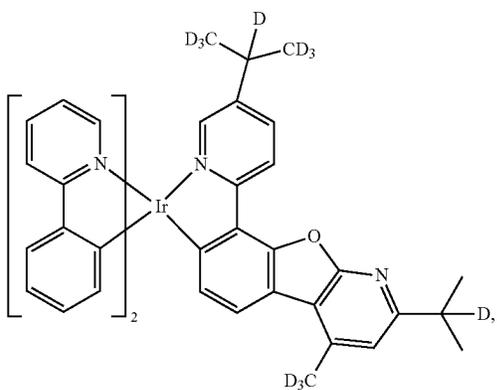
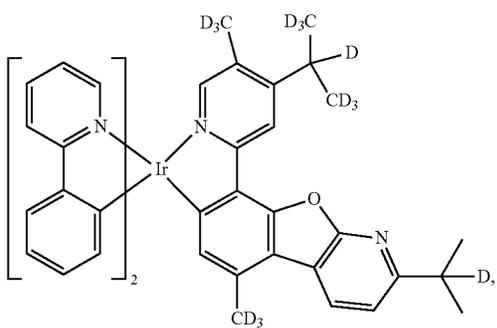
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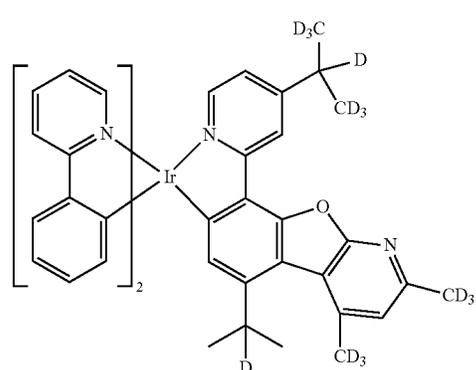
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**80**

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D69

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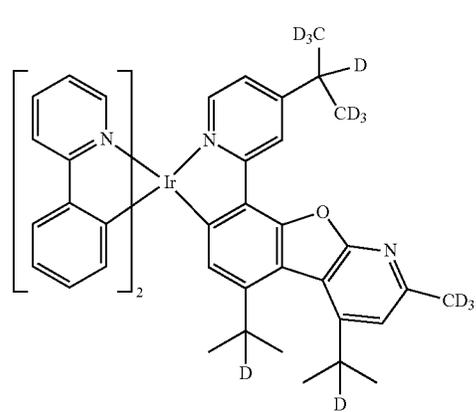
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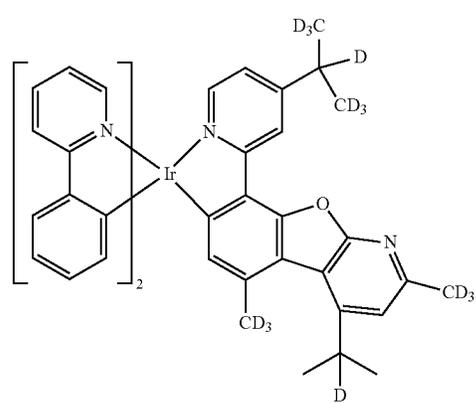
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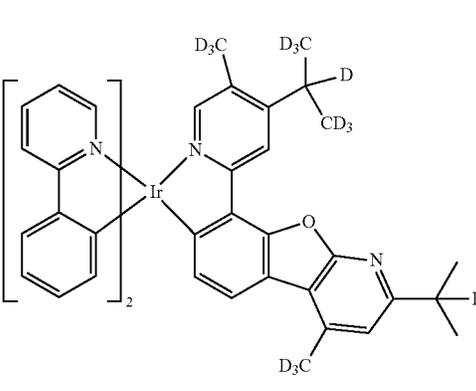
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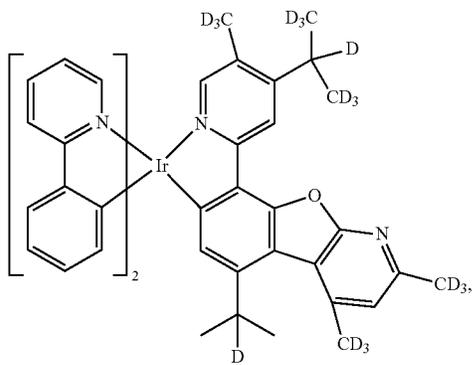
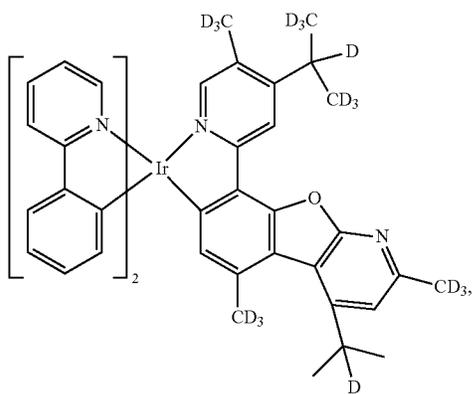
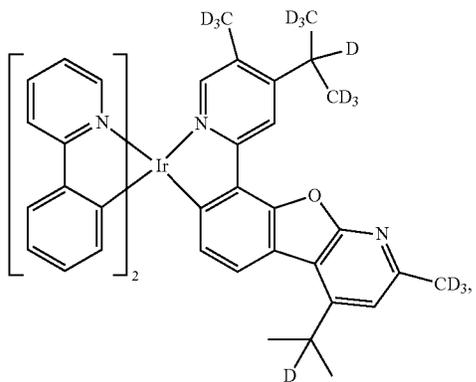
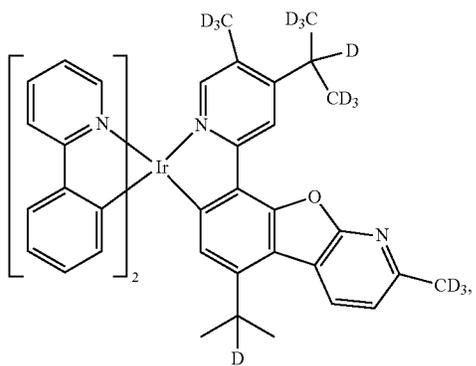
D71



D72

**81**

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**82**

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D73

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D74

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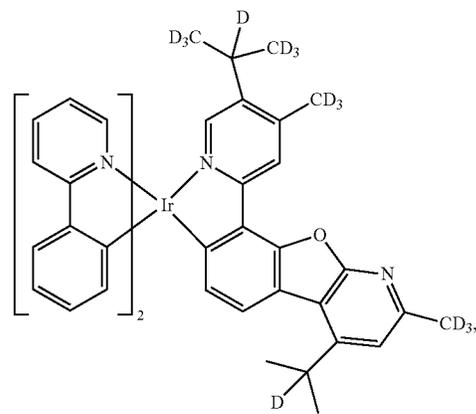
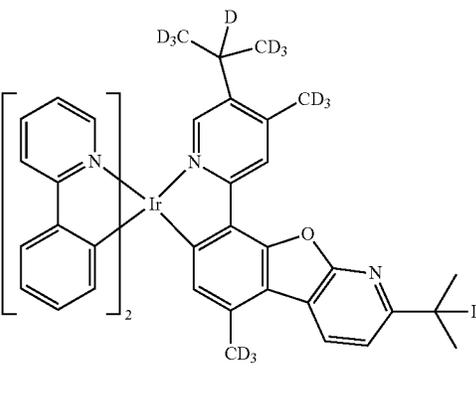
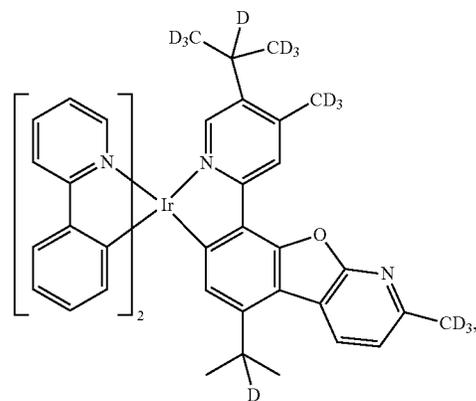
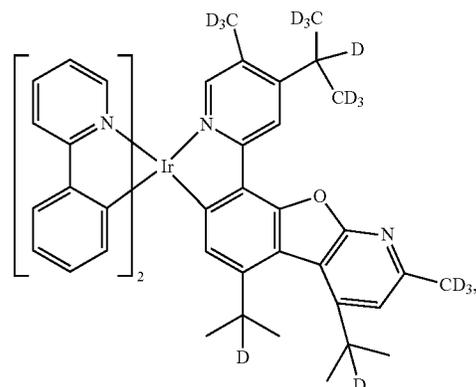
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D77



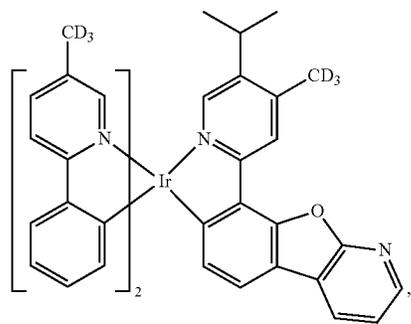
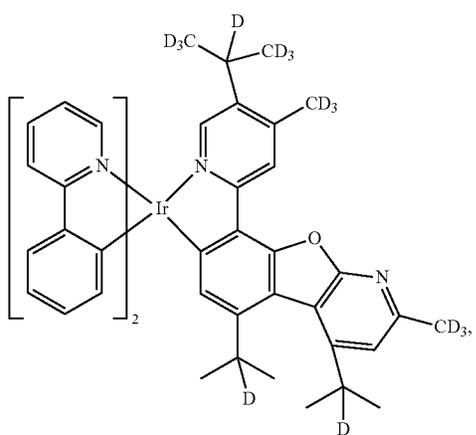
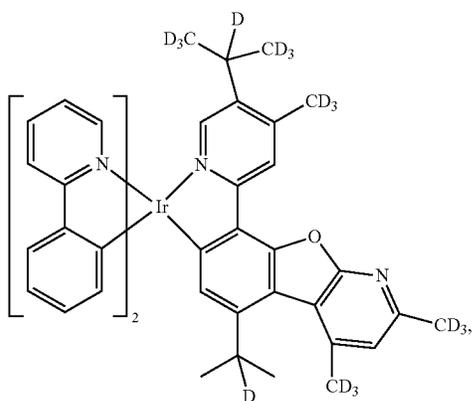
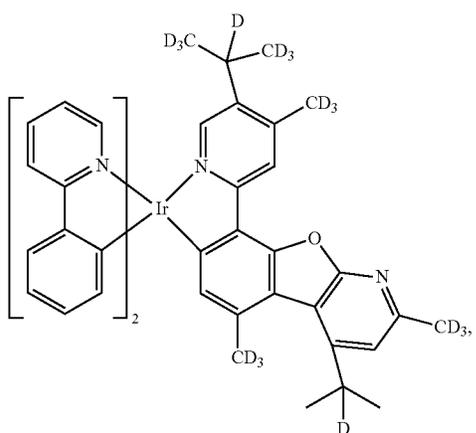
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D79

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**83**

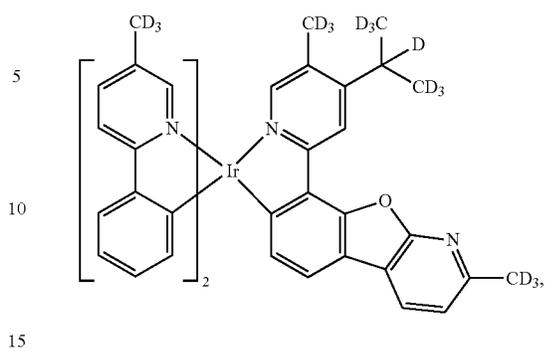
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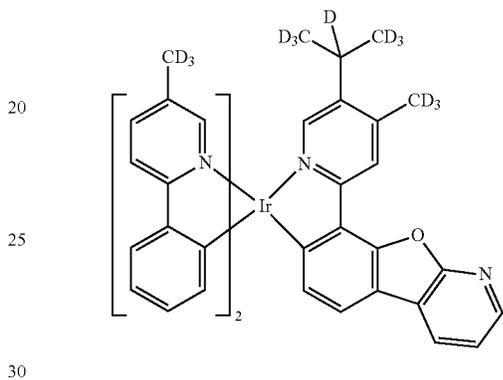
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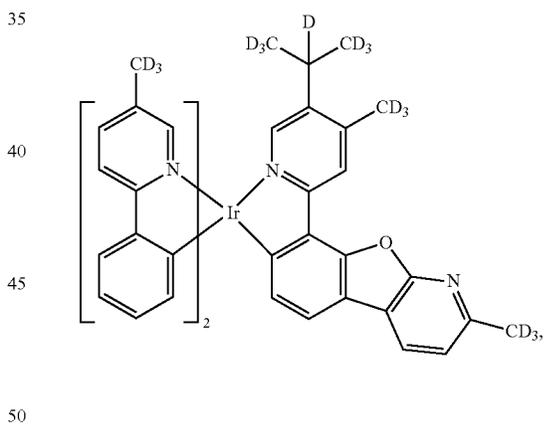
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D82



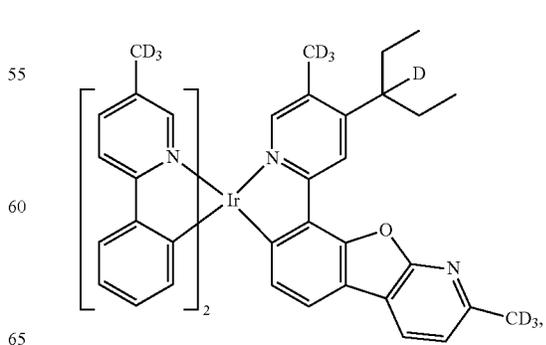
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D83



D87

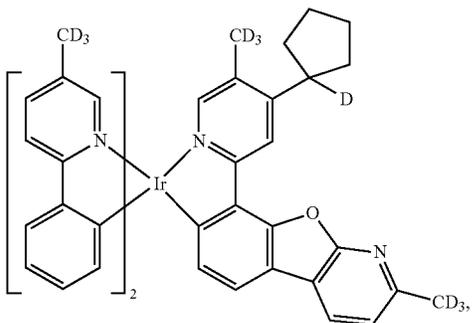
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D88

**85**

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D89

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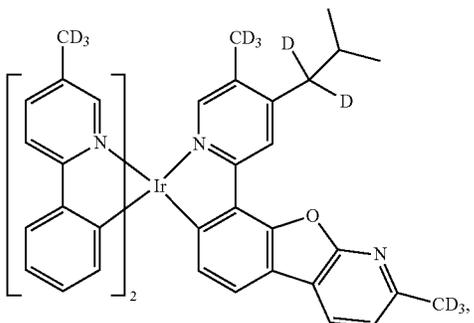
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D90

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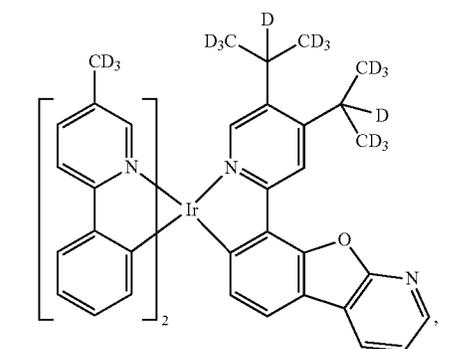
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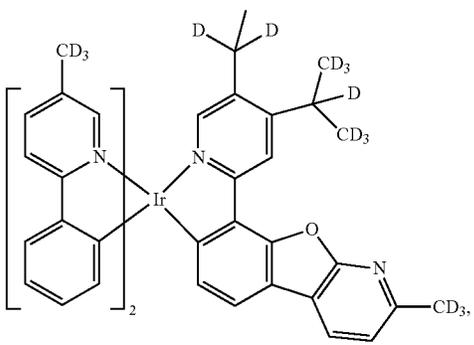


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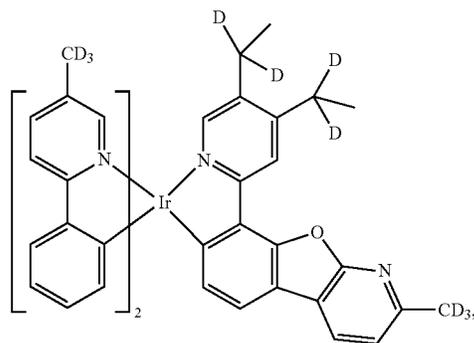
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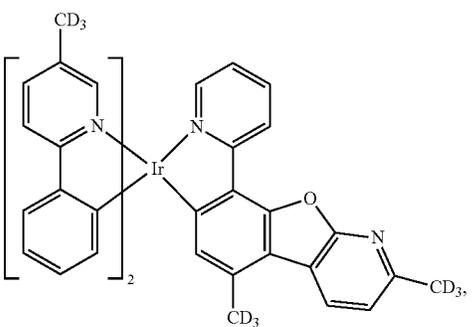
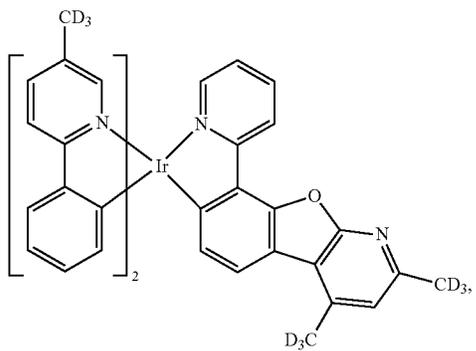
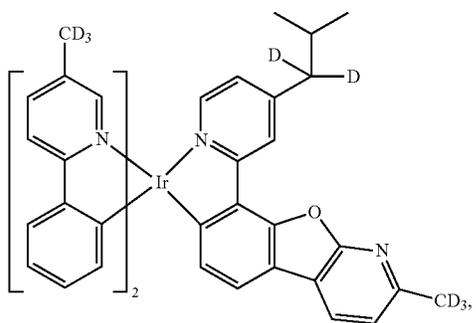
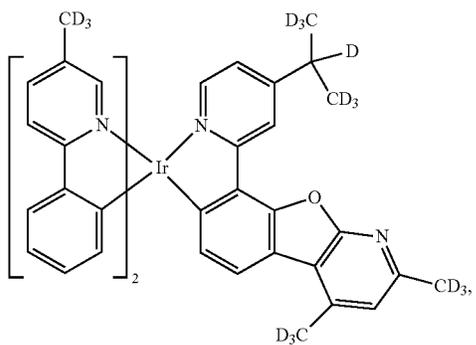
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D96

**87**

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**88**

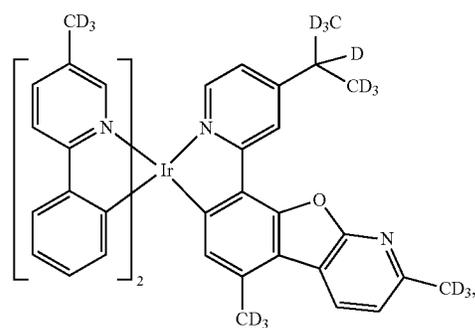
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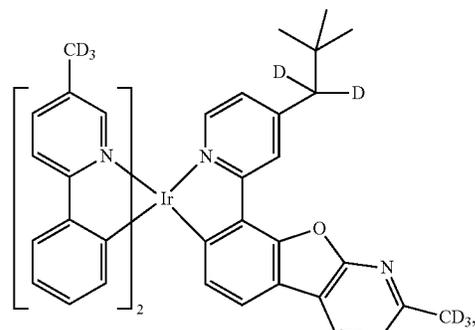


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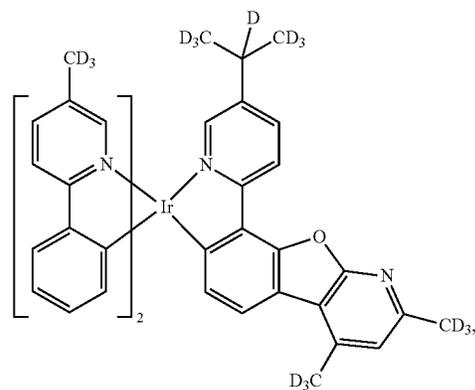
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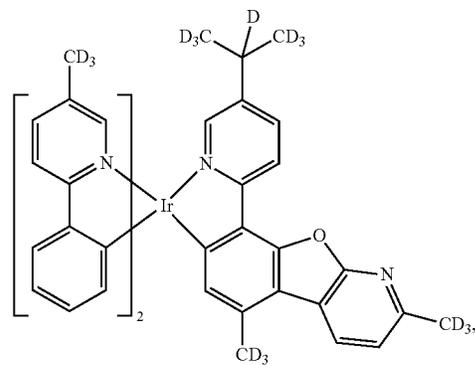


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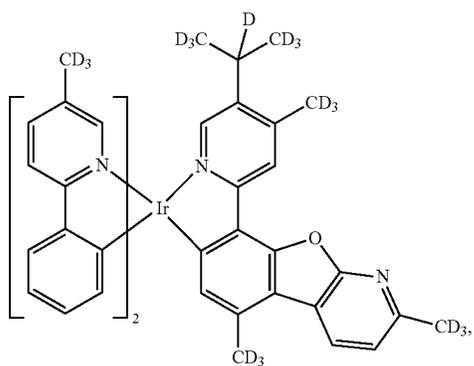
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D103

D104

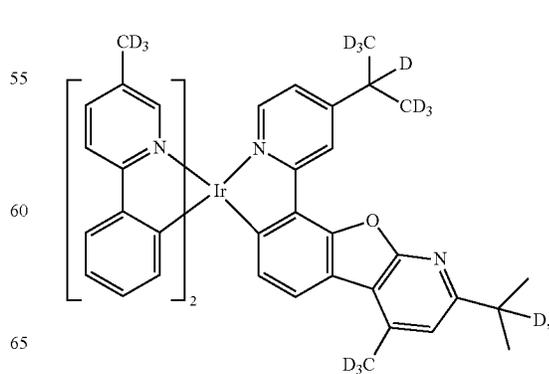
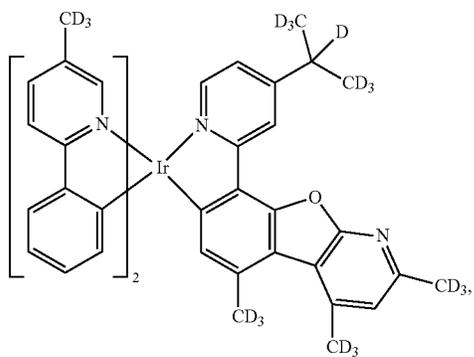
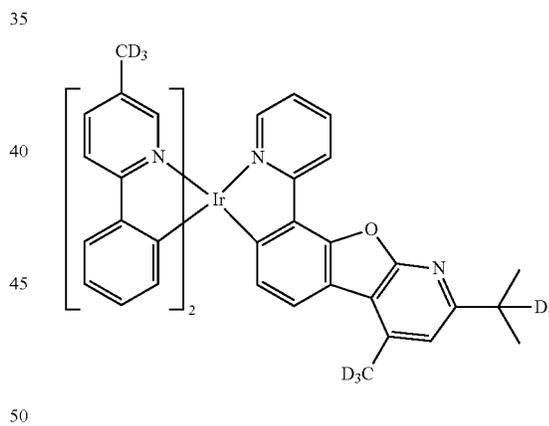
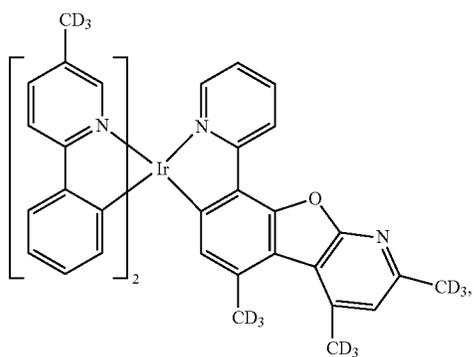
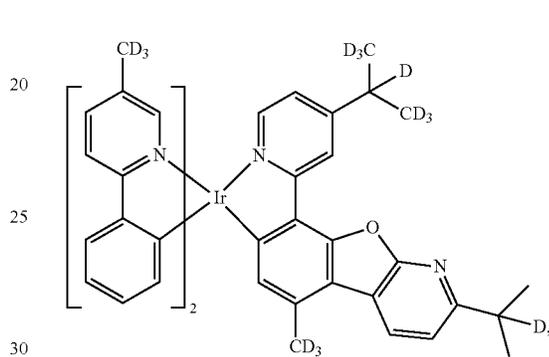
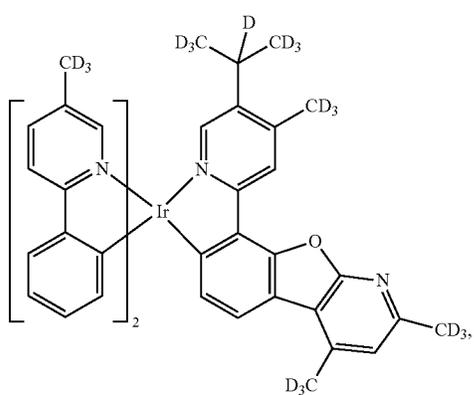
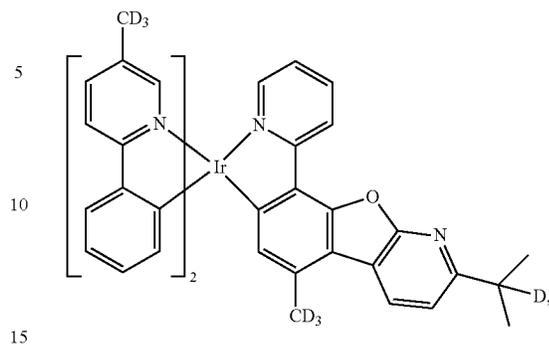
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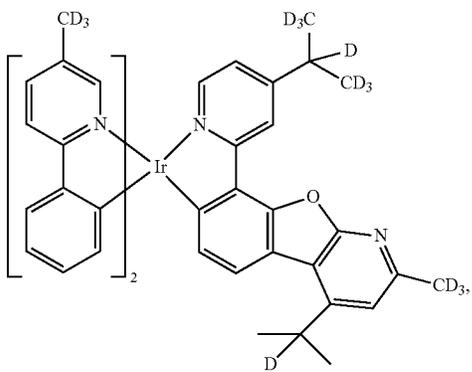
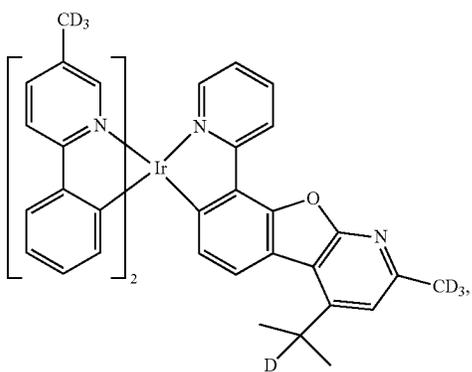
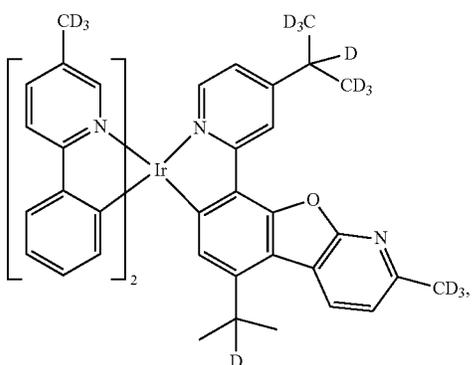
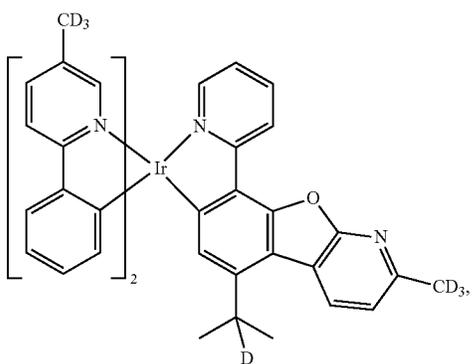
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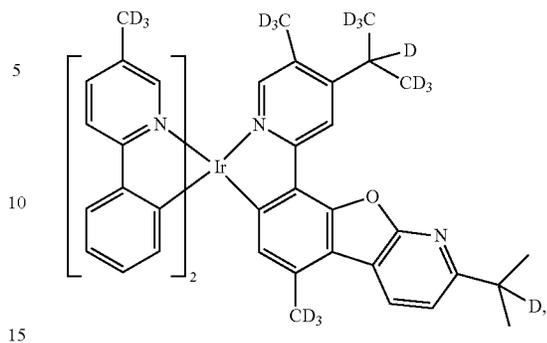
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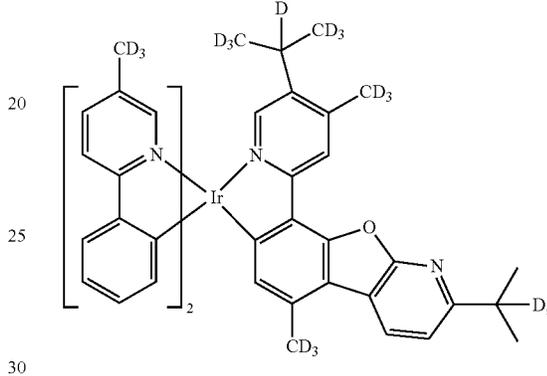
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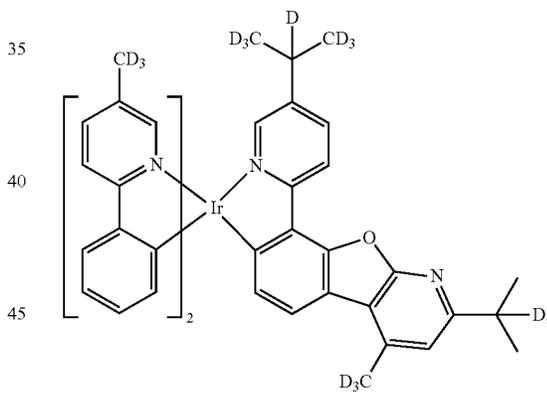
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D114



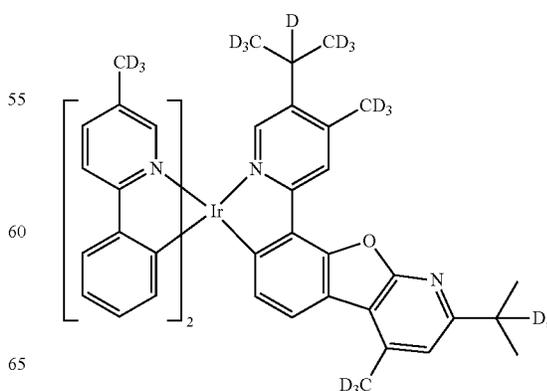
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D115



D119

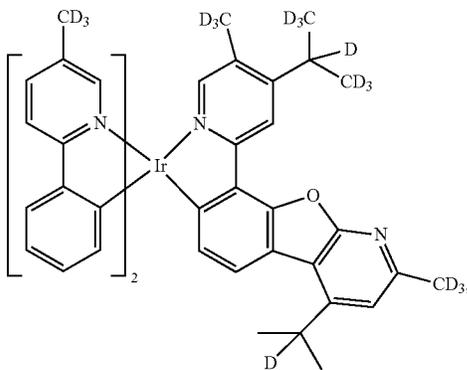
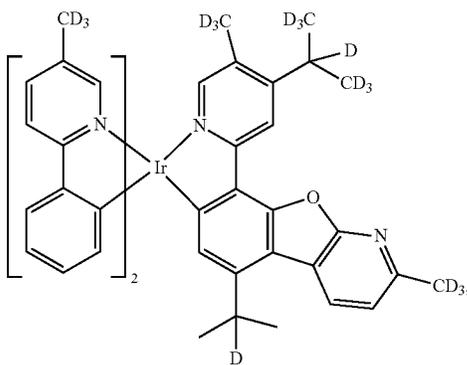
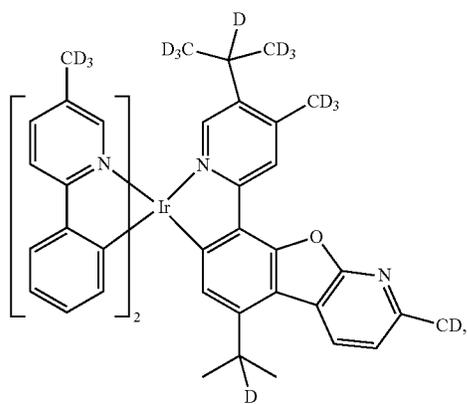
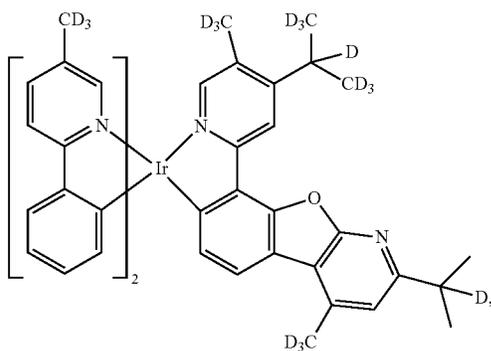
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D120

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**94**

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D121

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D122

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D123

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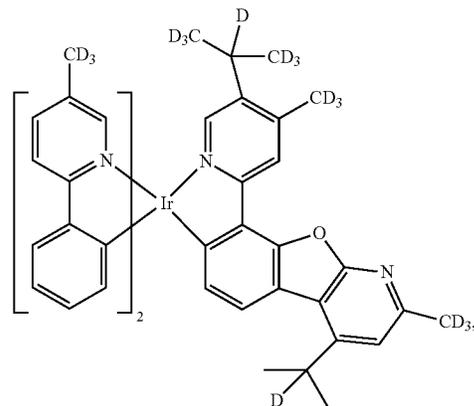
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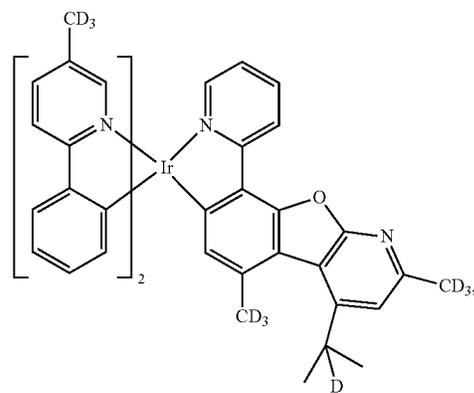
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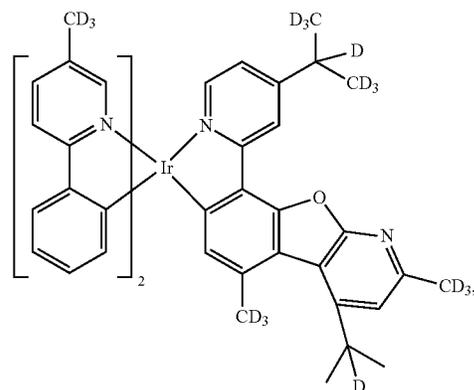
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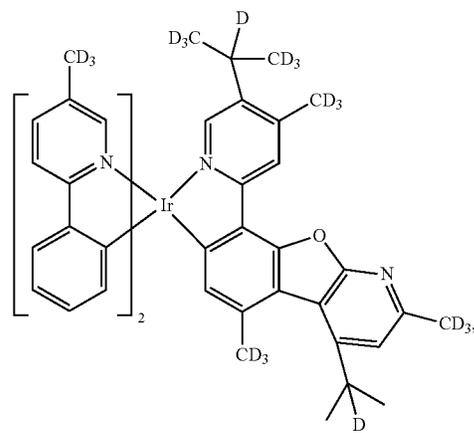
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D127

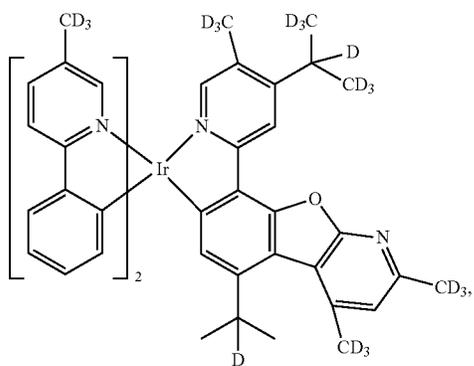
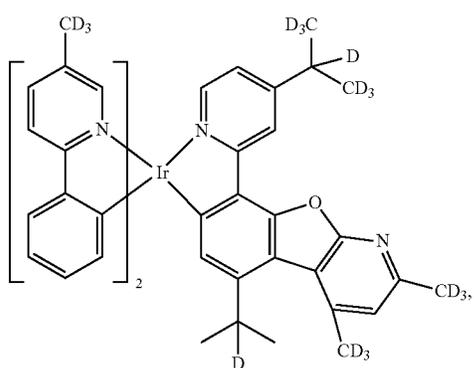
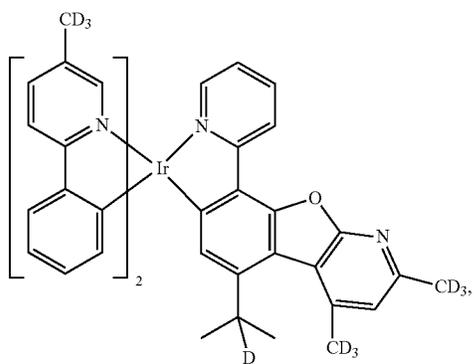
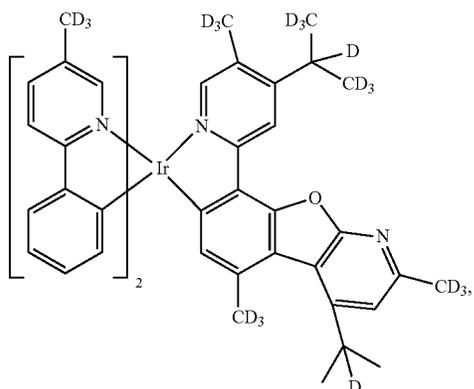


D128



**95**

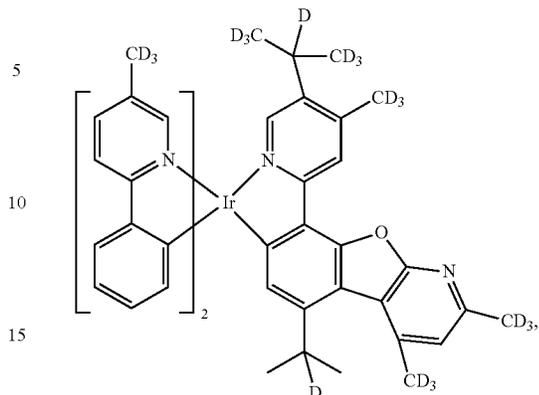
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**96**

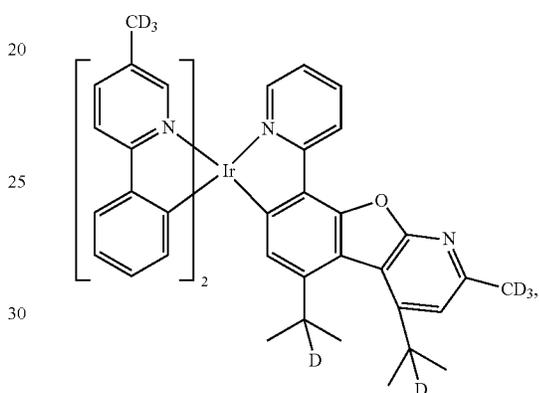
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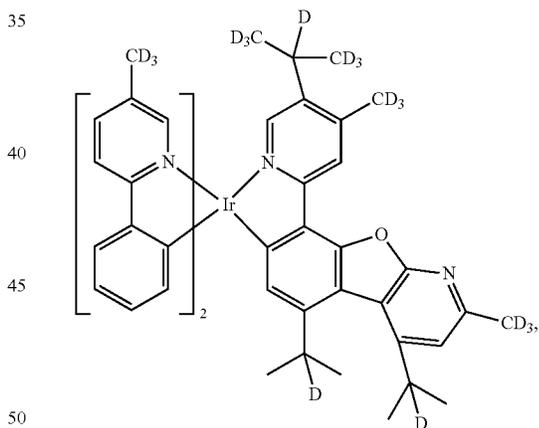
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D130



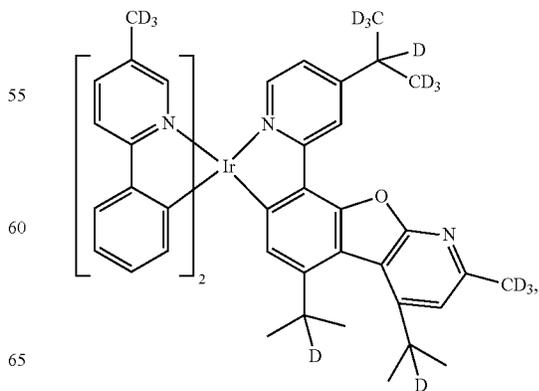
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D131



D135

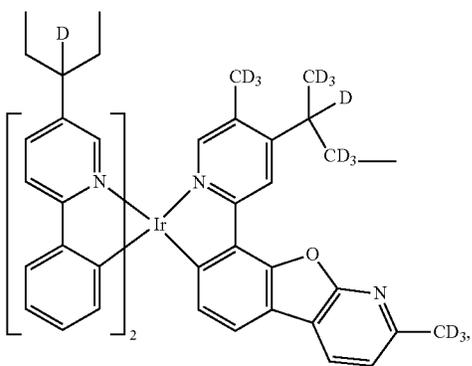
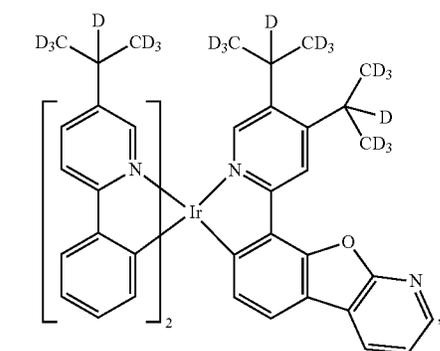
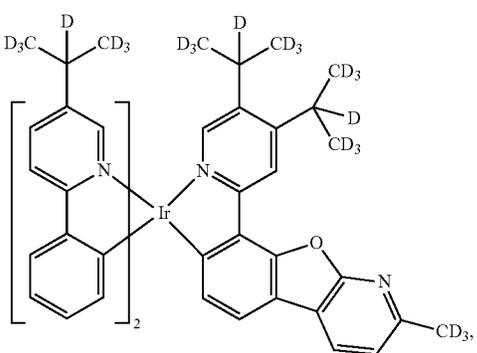
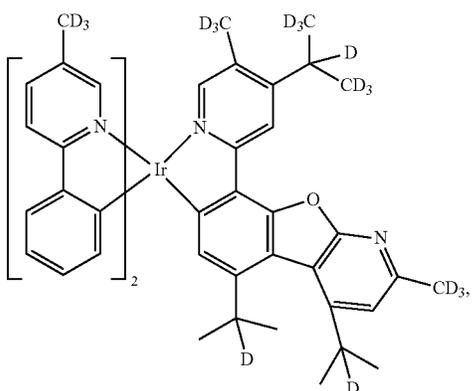
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D136

**97**

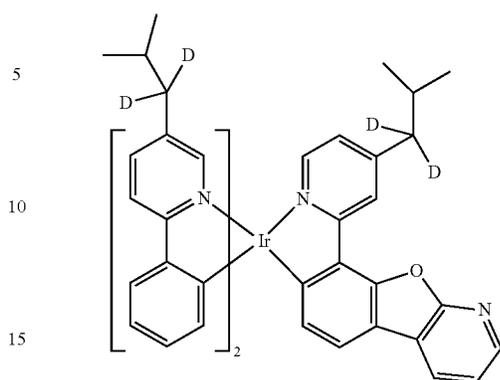
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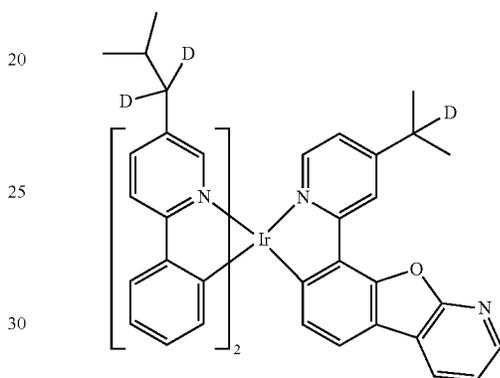
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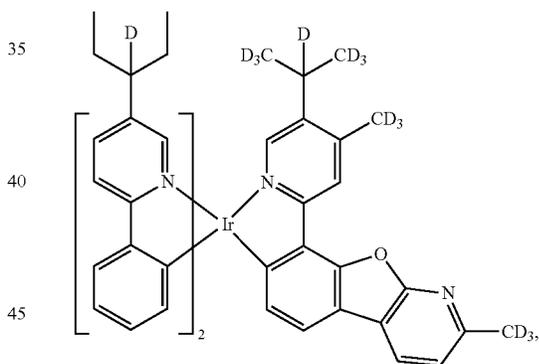
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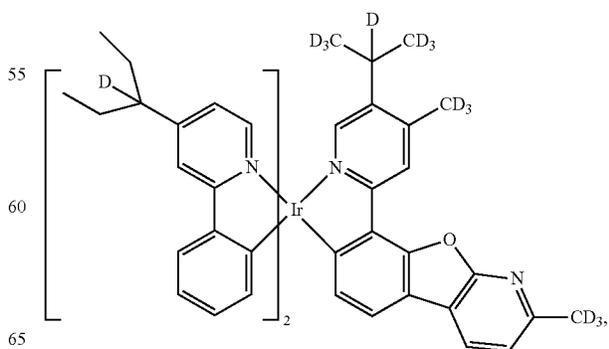
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D139



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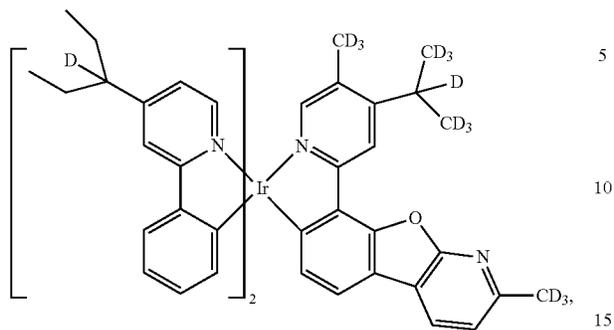
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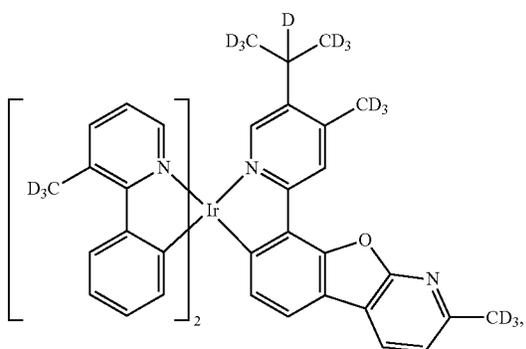
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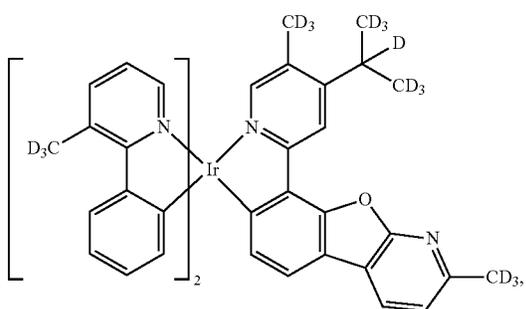
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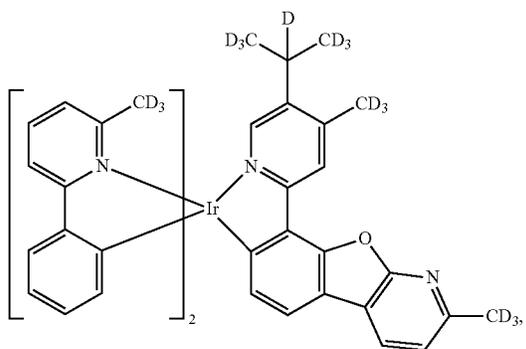
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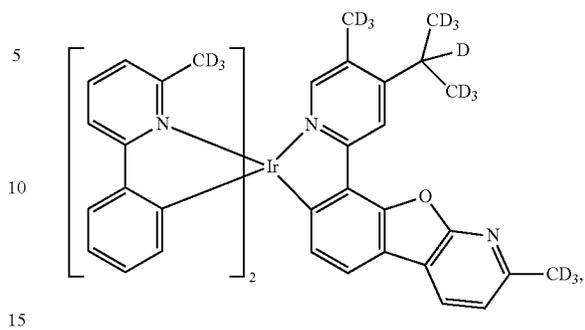


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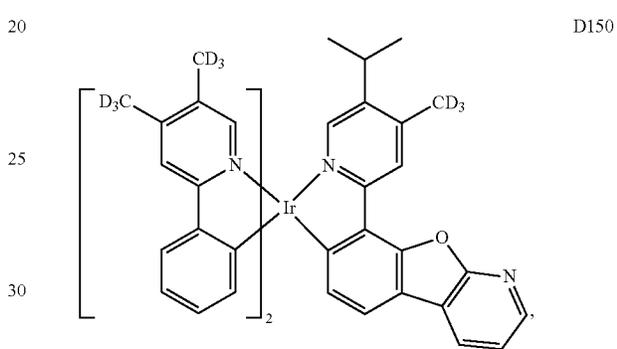


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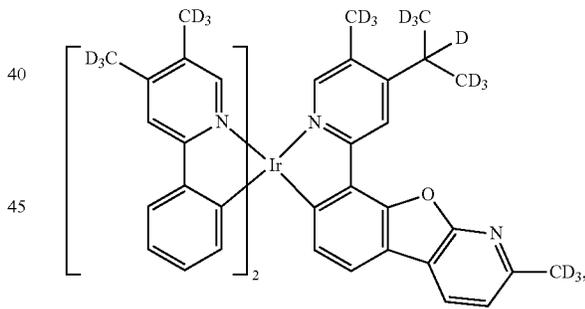
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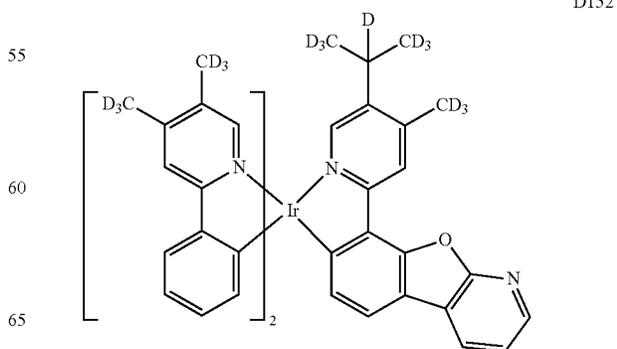
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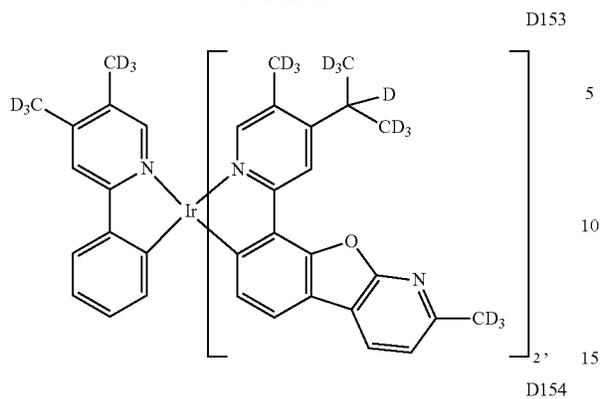


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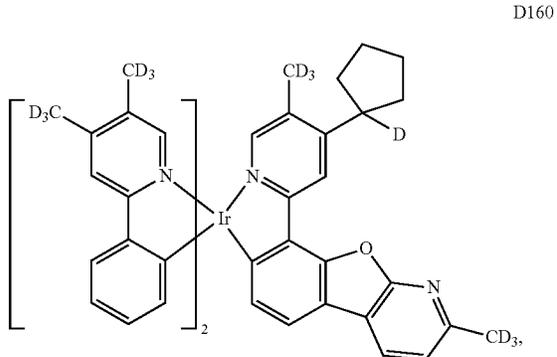
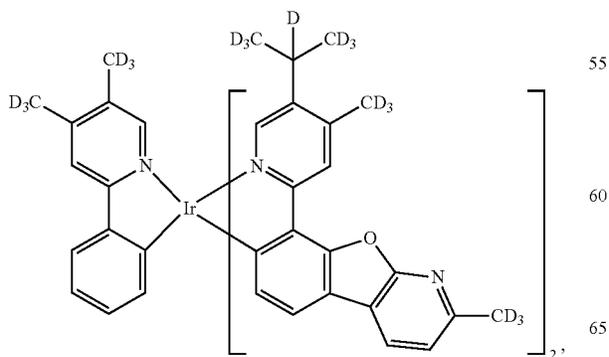
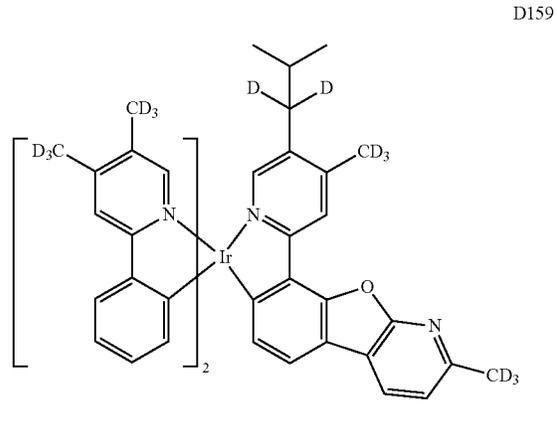
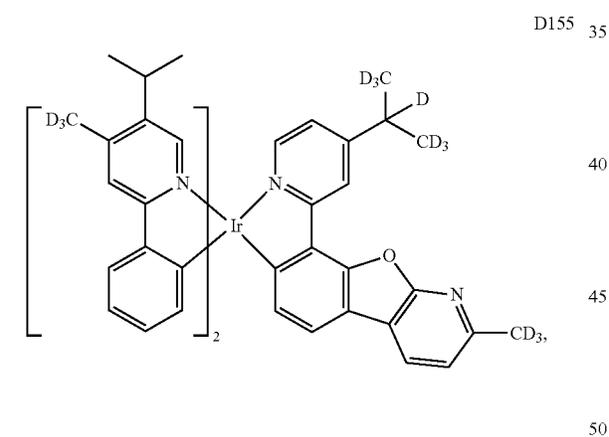
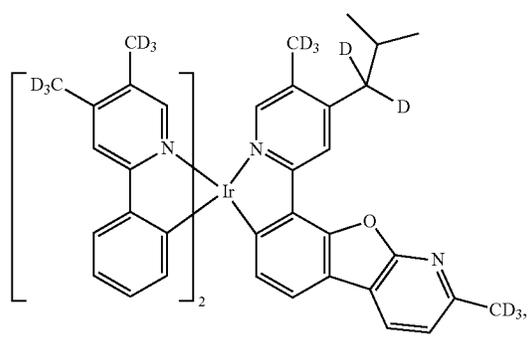
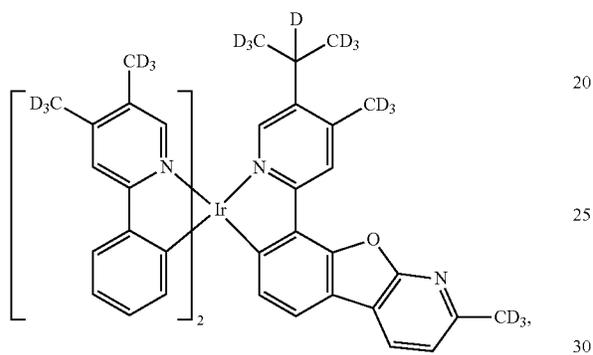
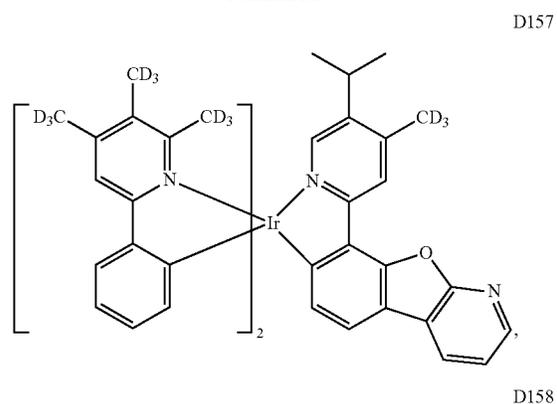
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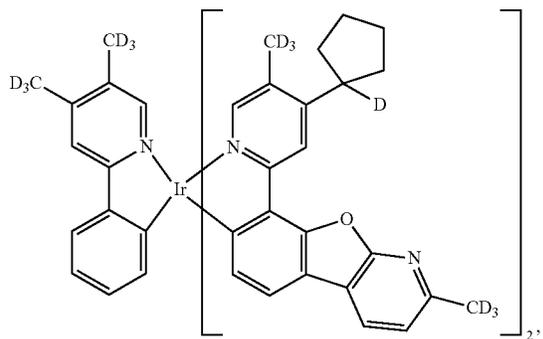
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D161



D162

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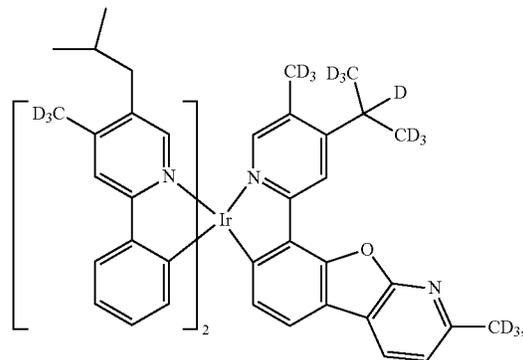
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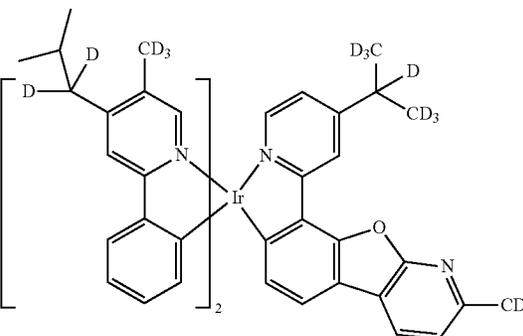


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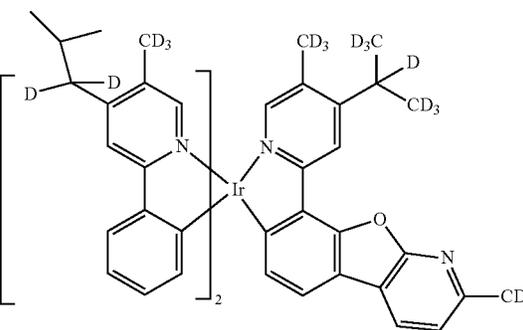


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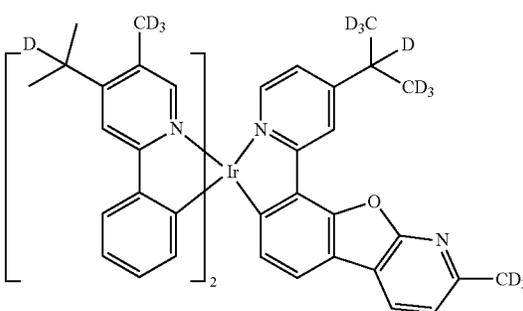
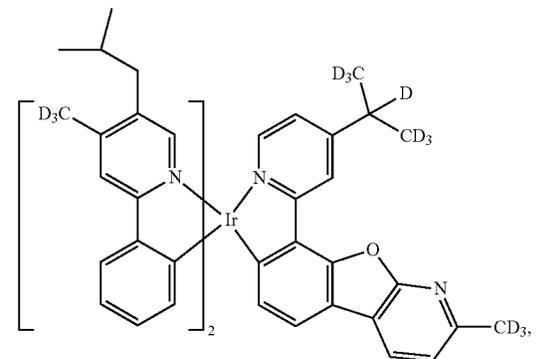
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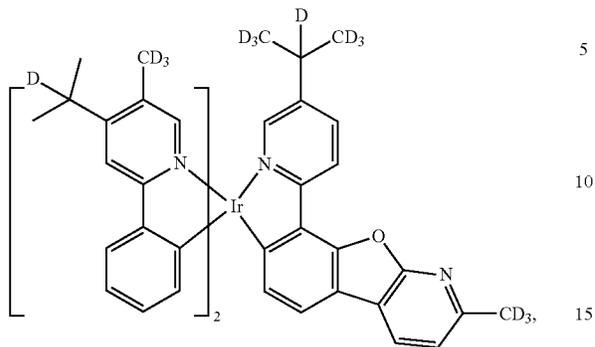
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D168

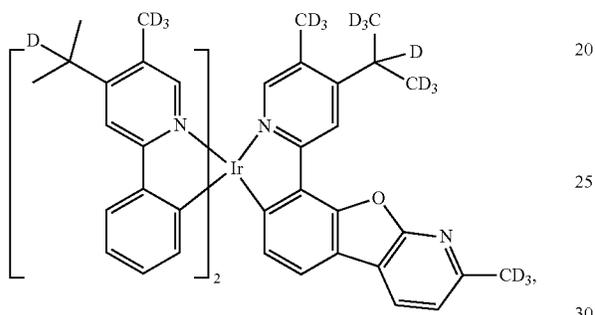


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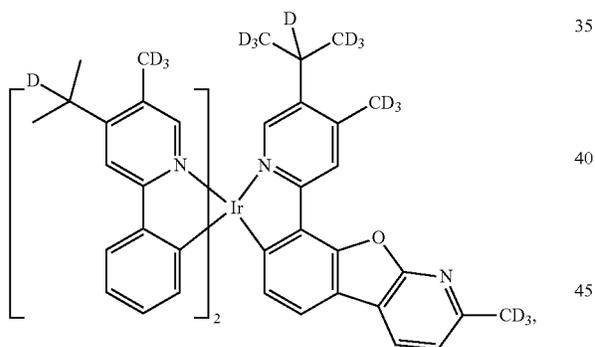
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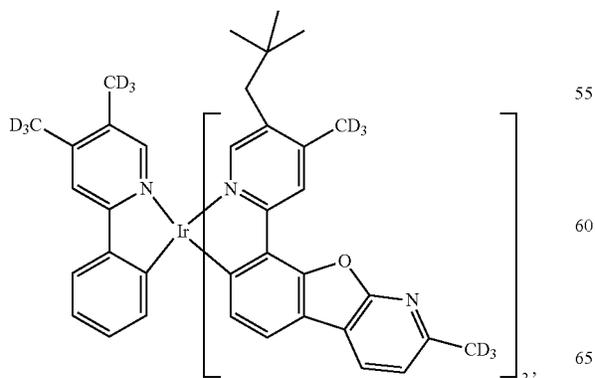
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D171

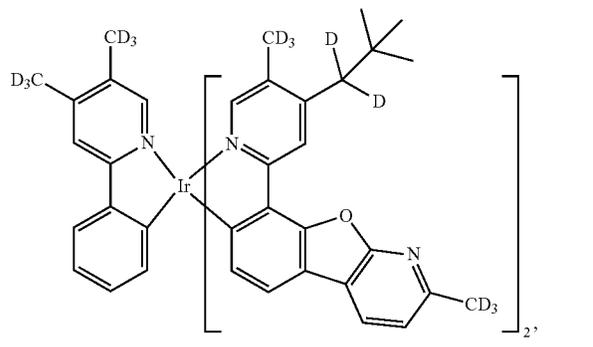


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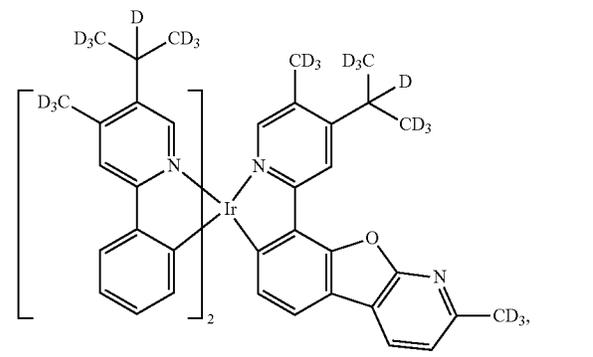


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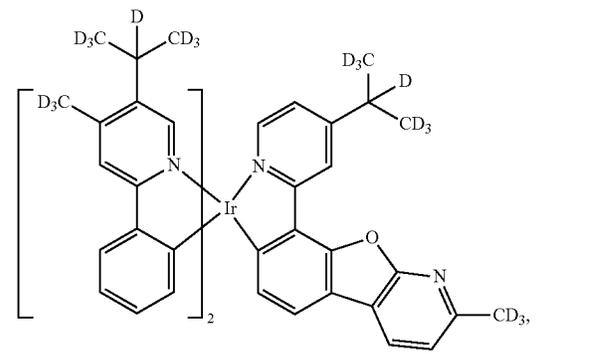
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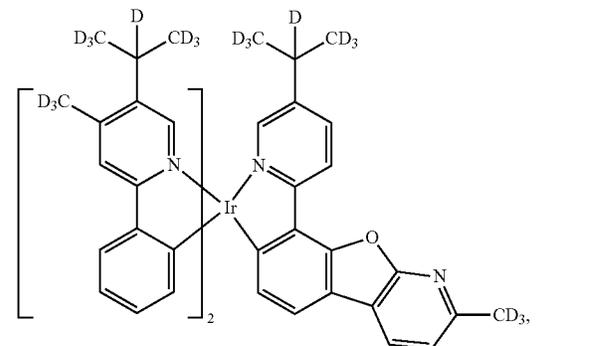
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D175

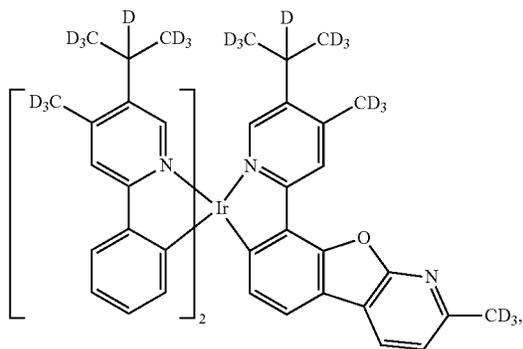


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**107**  
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D177



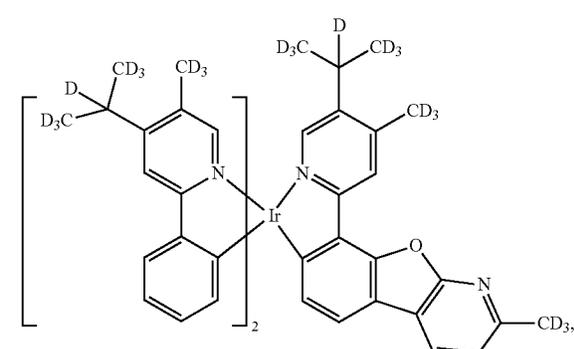
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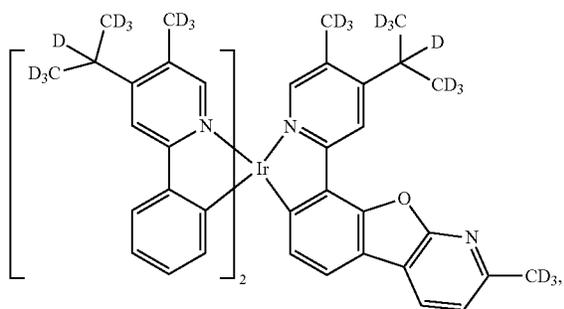
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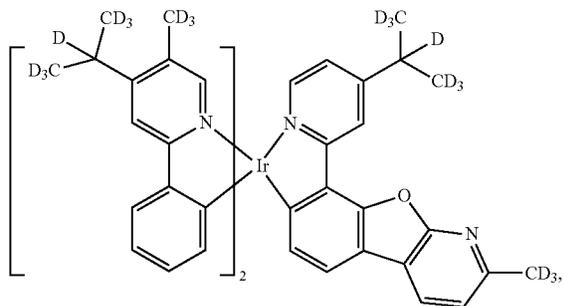
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D178



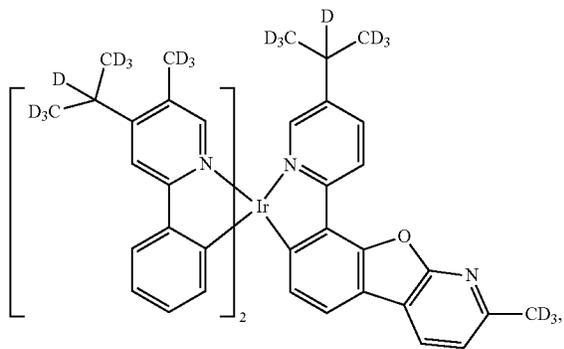
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D179



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D180

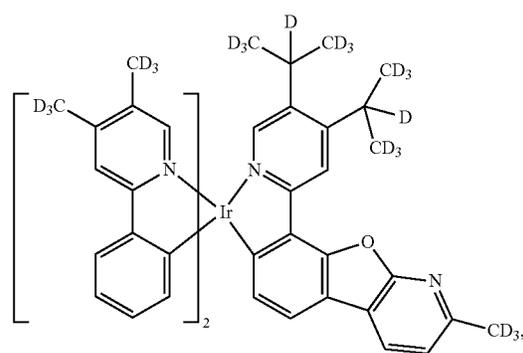


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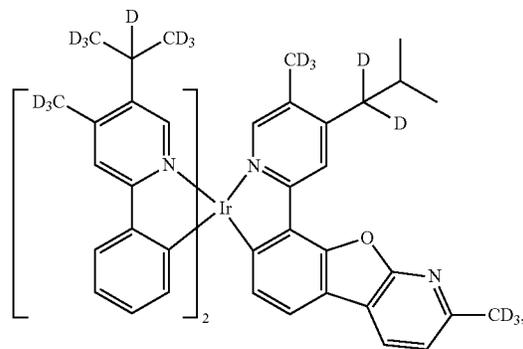
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D183



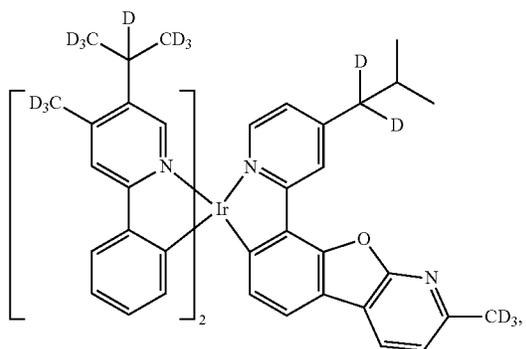
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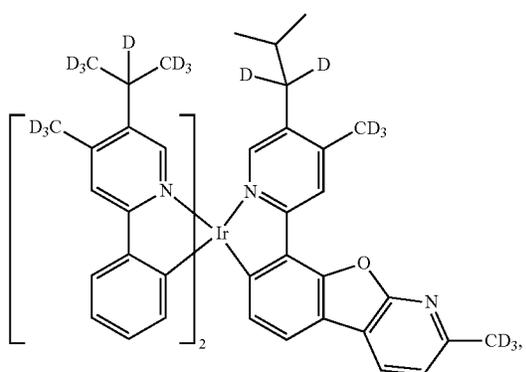
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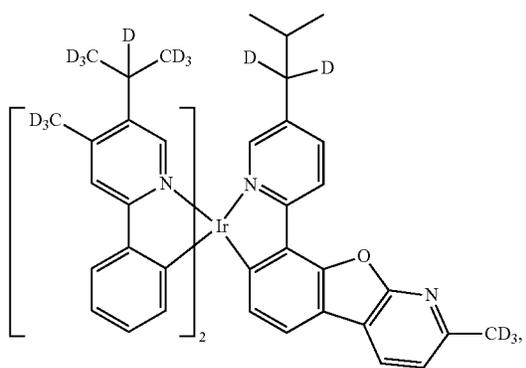
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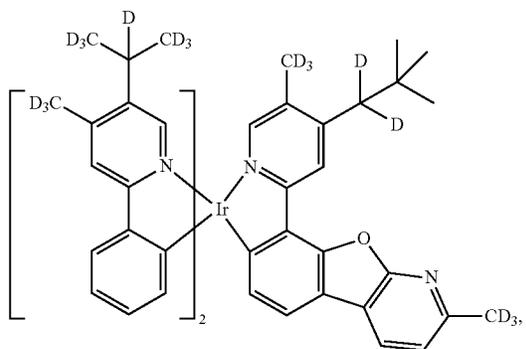
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D187



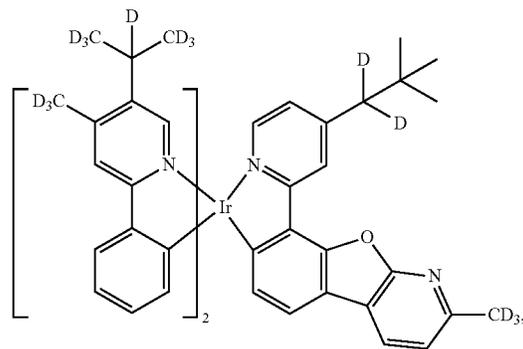
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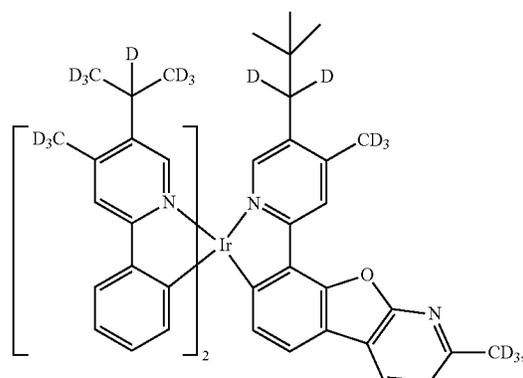
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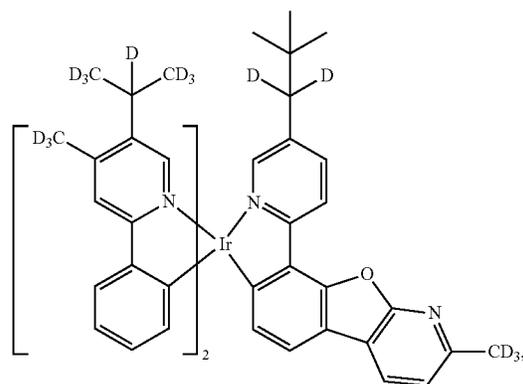
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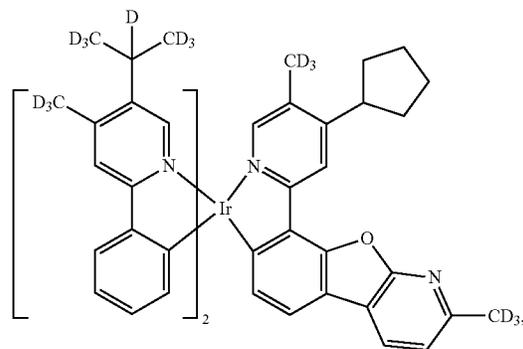
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D191



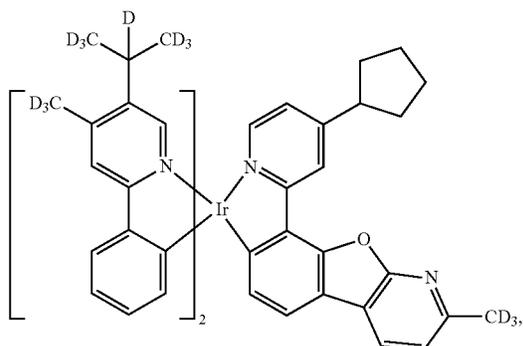
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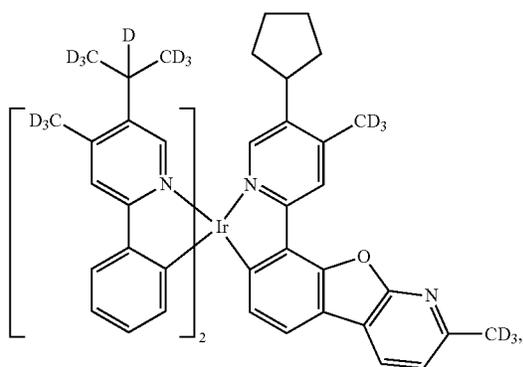
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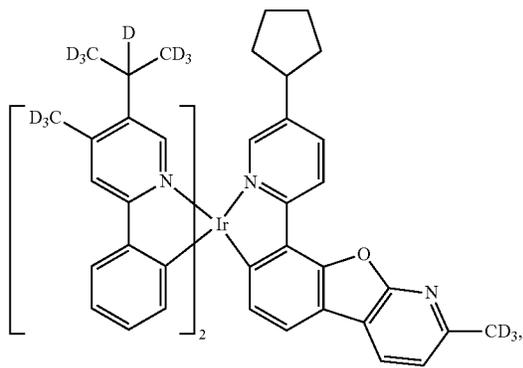
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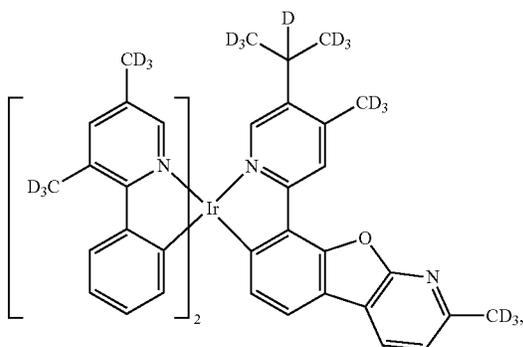
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D195



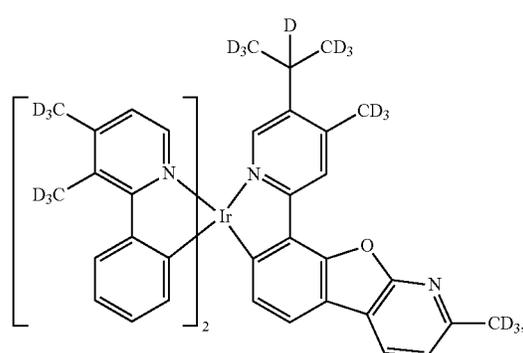
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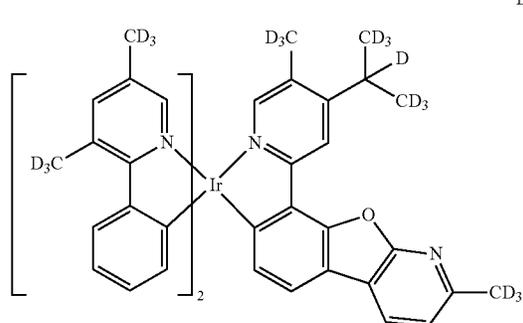
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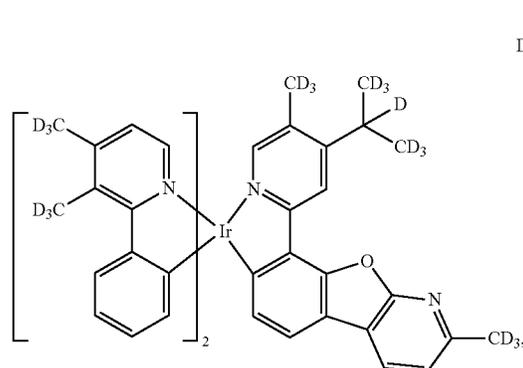
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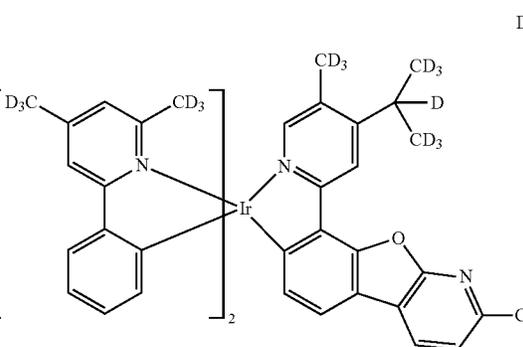
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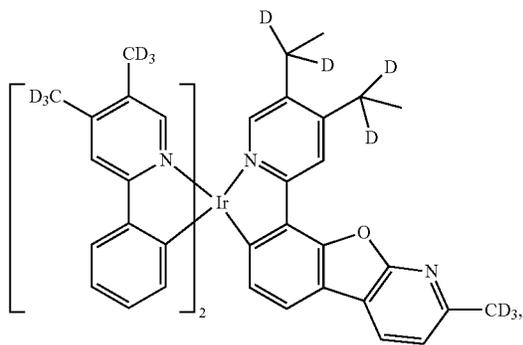
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D201

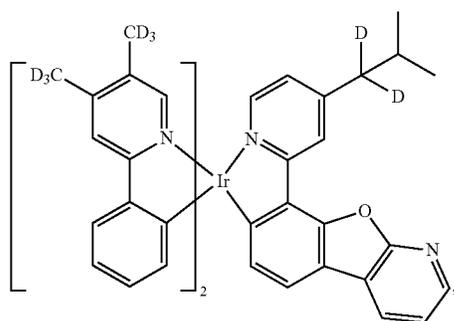


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D202

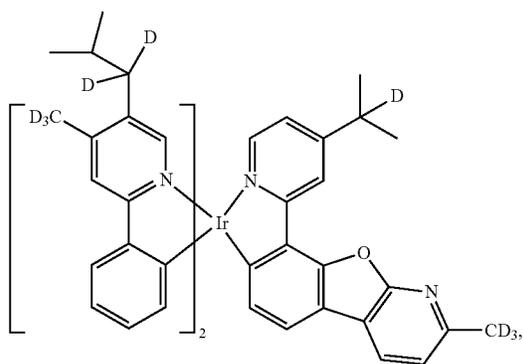


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D203



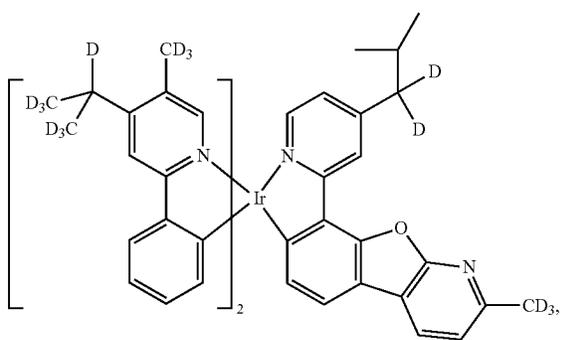
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D204



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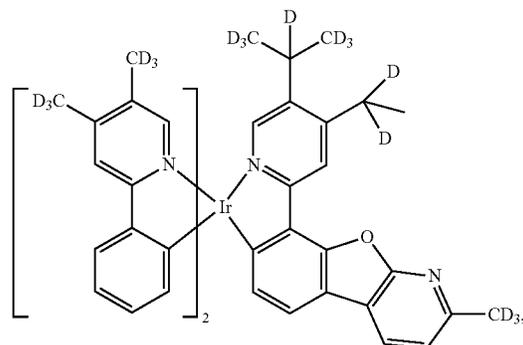
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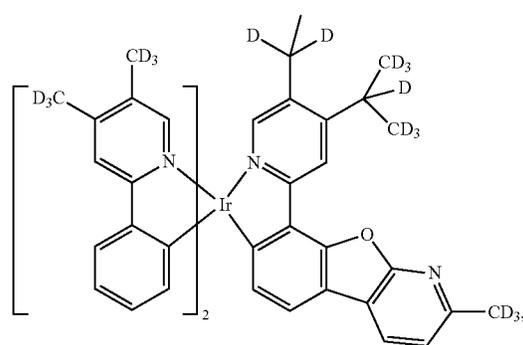


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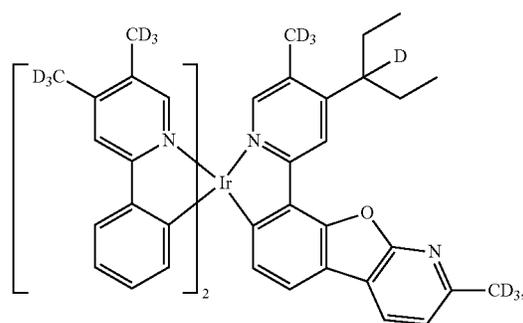


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D207



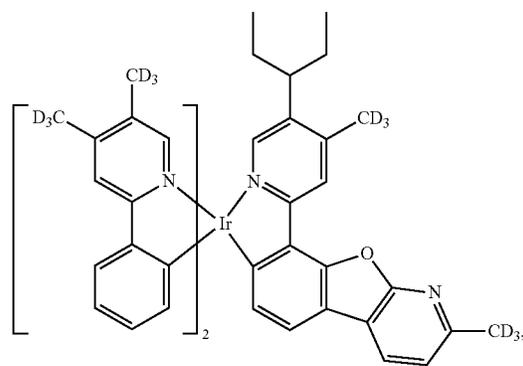
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D208



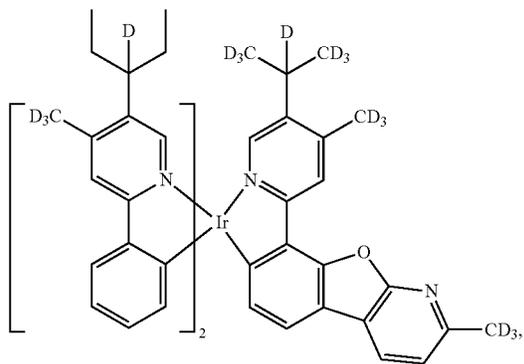
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D209



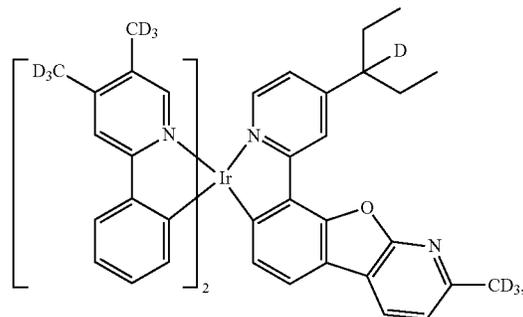
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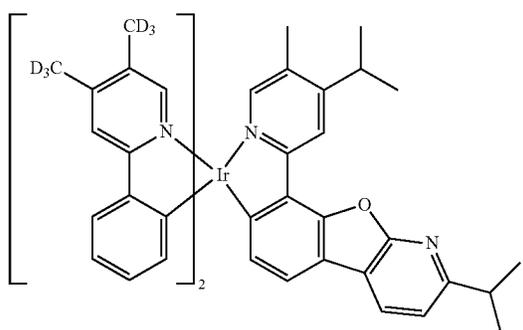
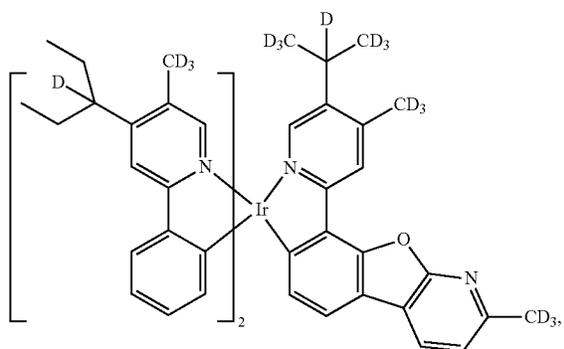


D210

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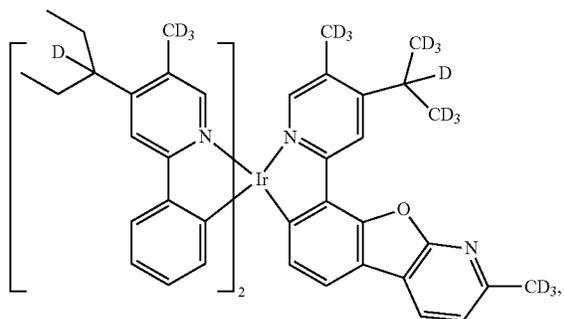
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D211

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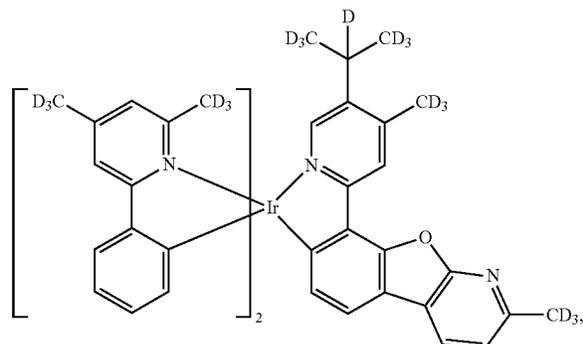
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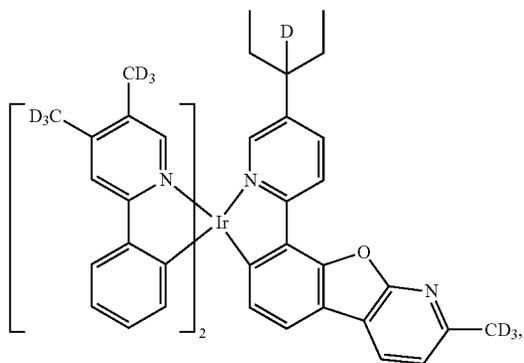
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D212

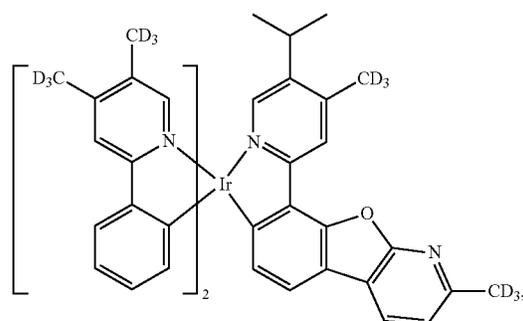
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D216



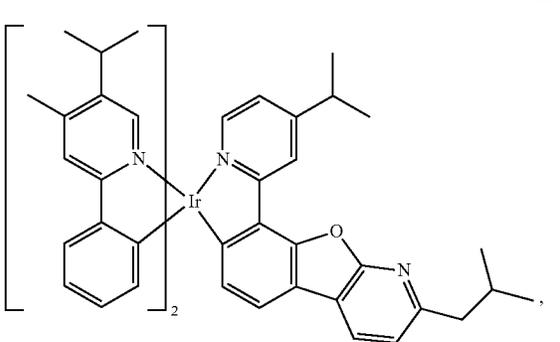
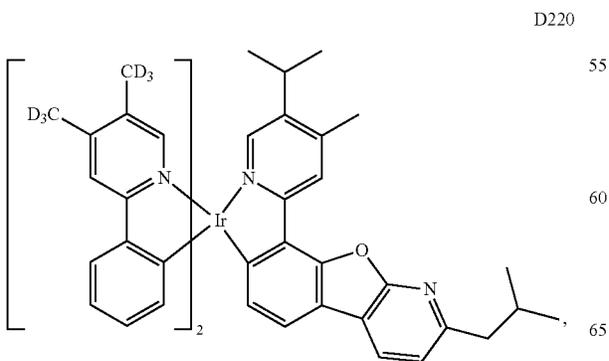
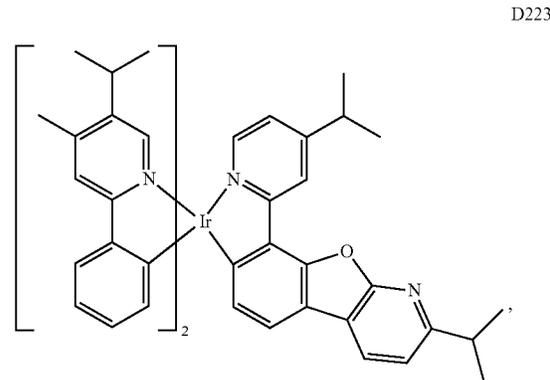
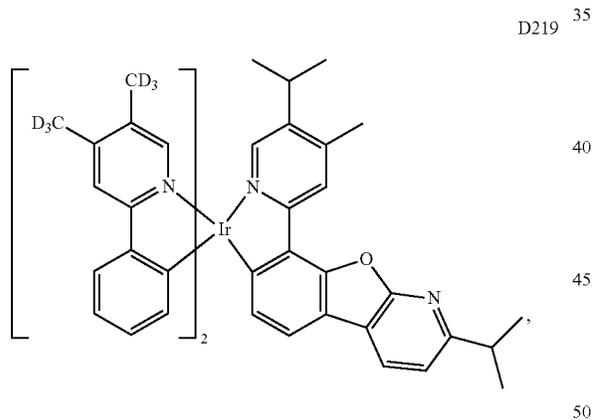
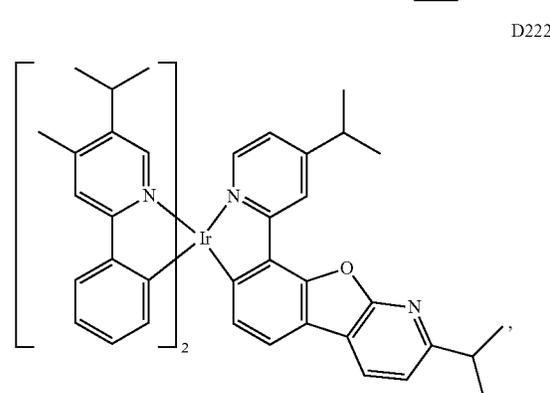
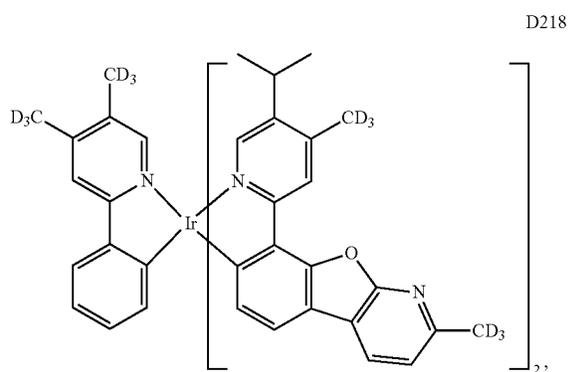
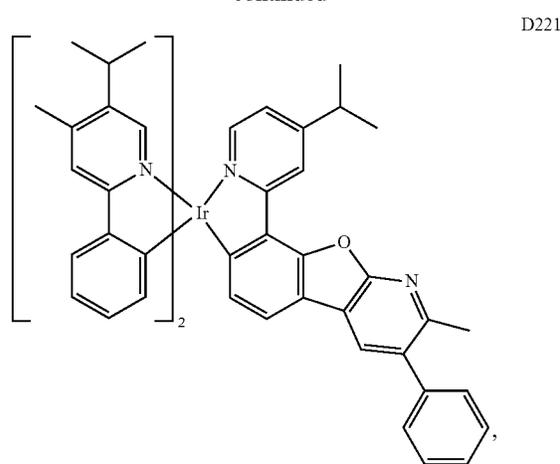
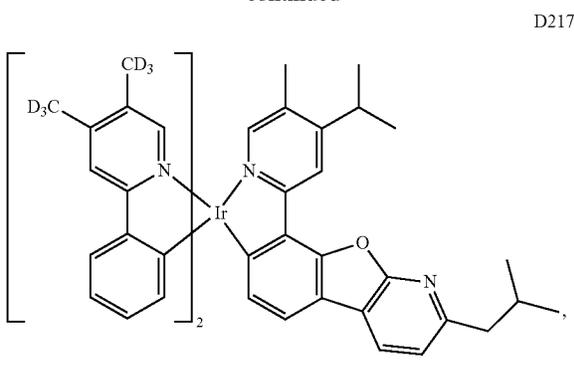
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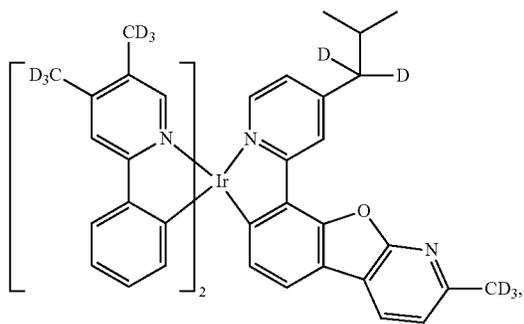
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119

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D225



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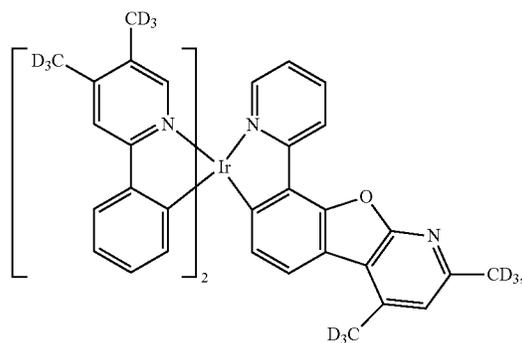
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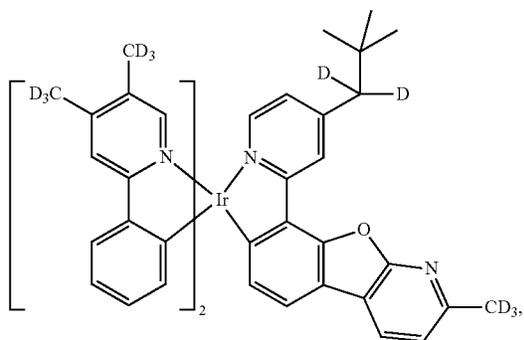


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D230



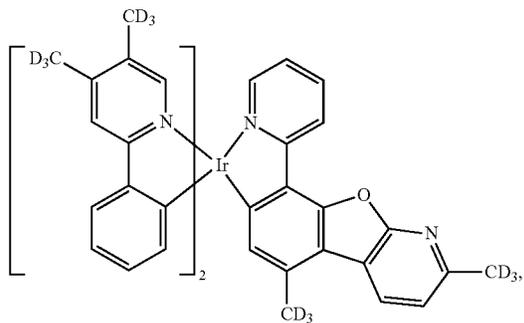
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D231



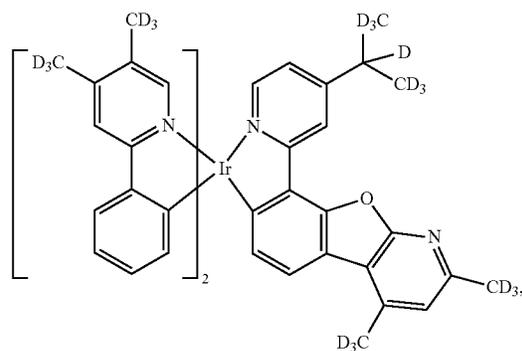
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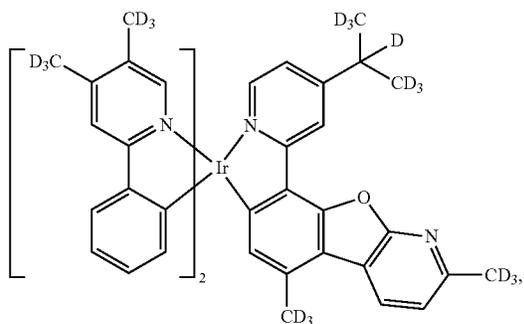
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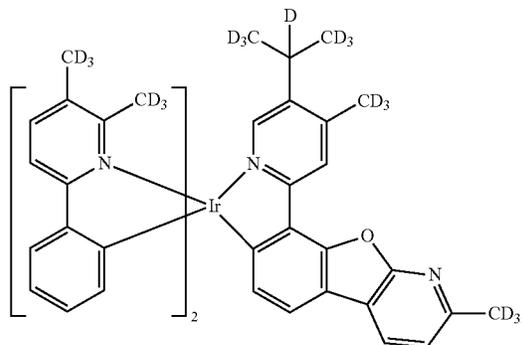


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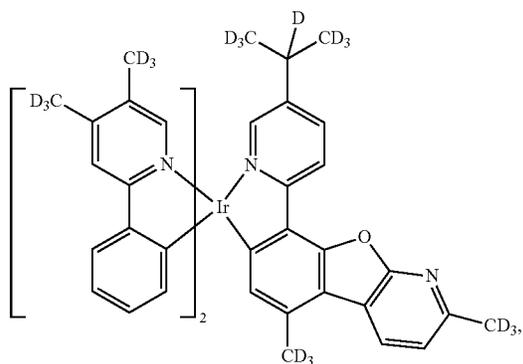
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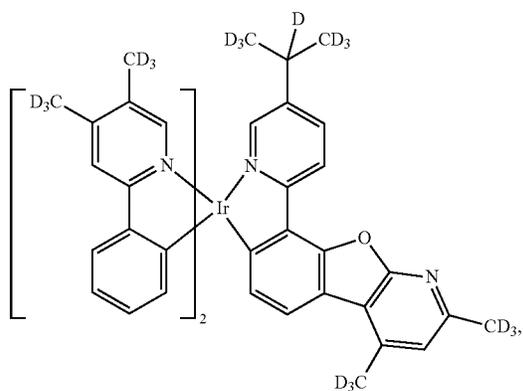
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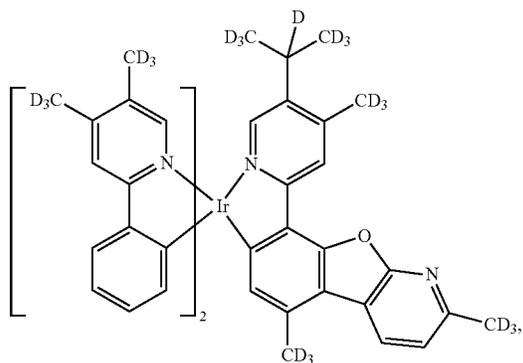
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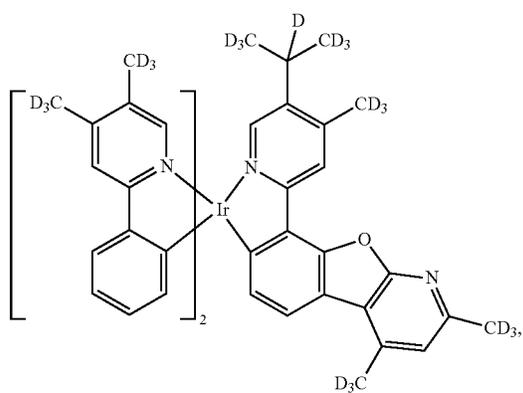
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D235



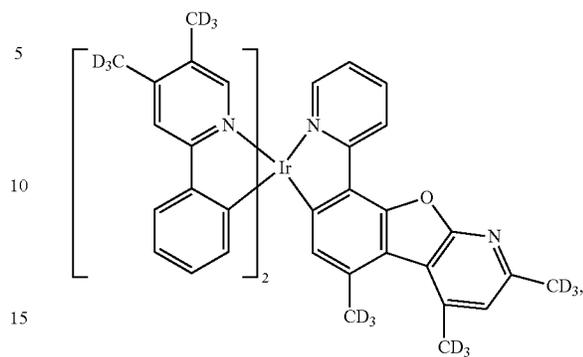
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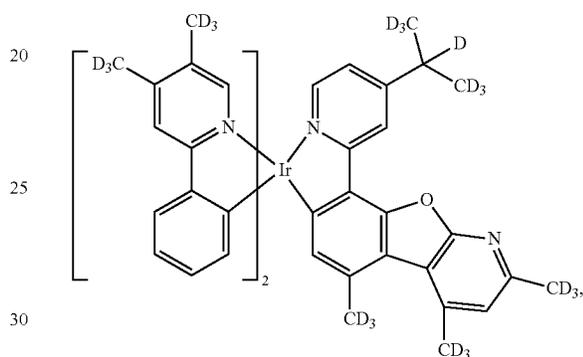
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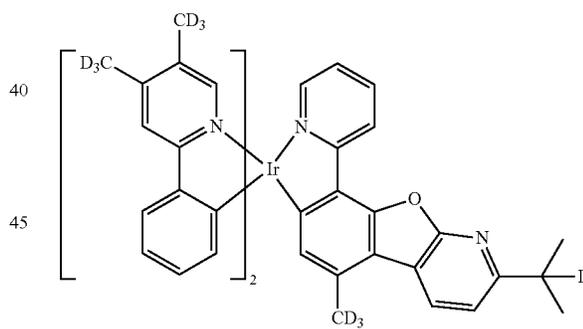


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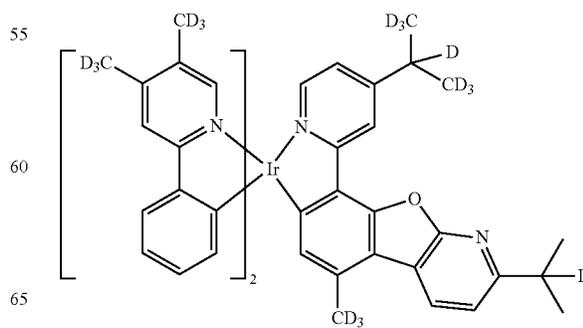
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D239



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D240

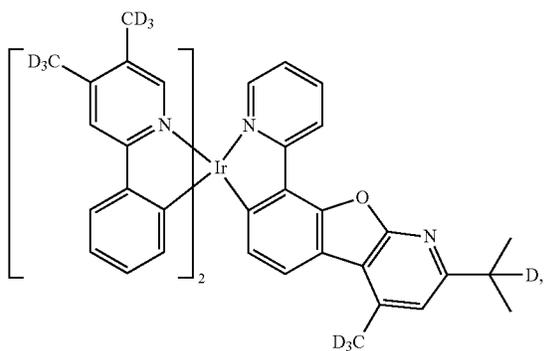


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**124**  
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D241

D245

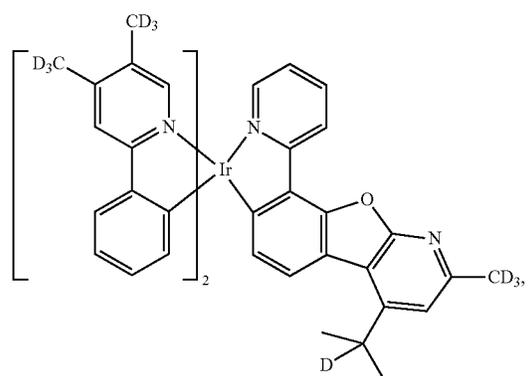


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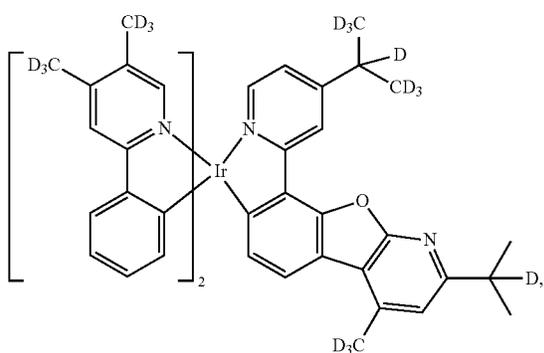


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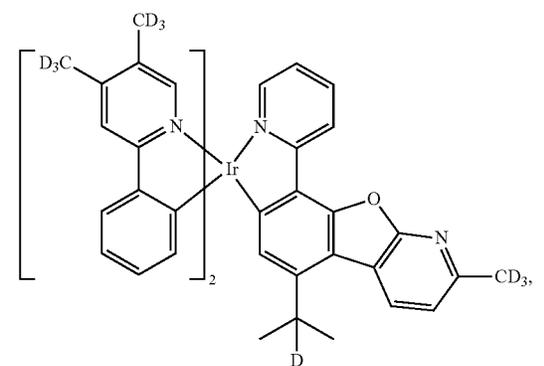


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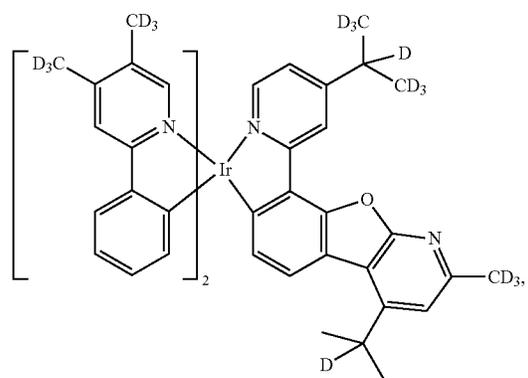
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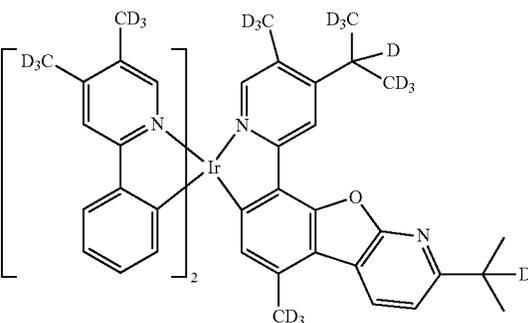


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D247



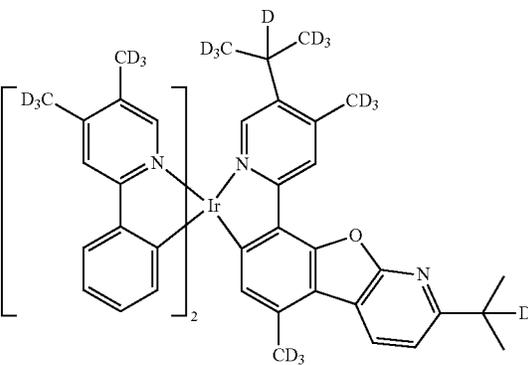
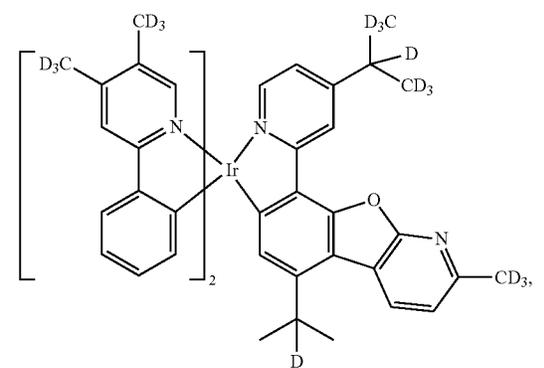
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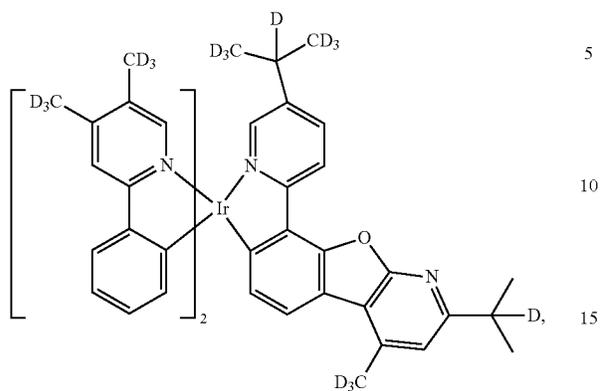
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D248



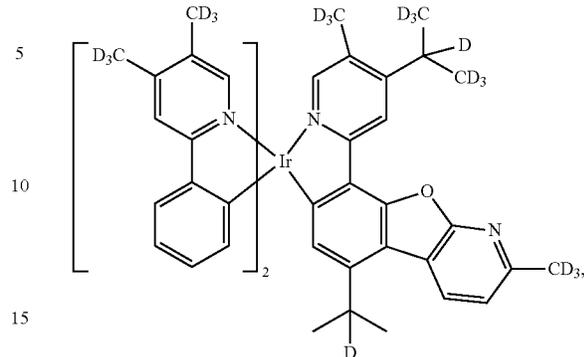
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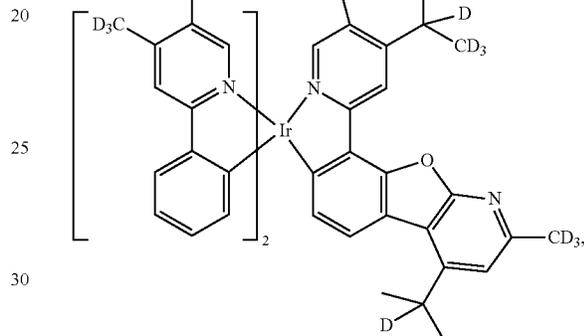
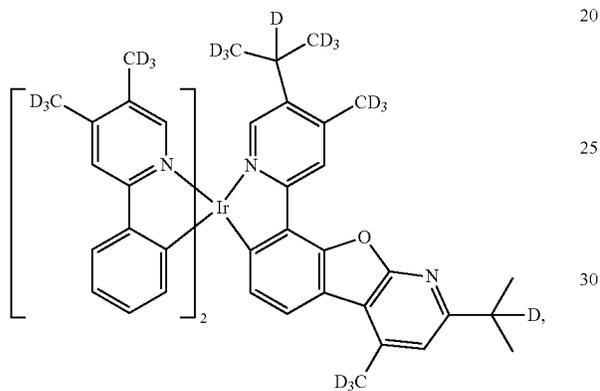
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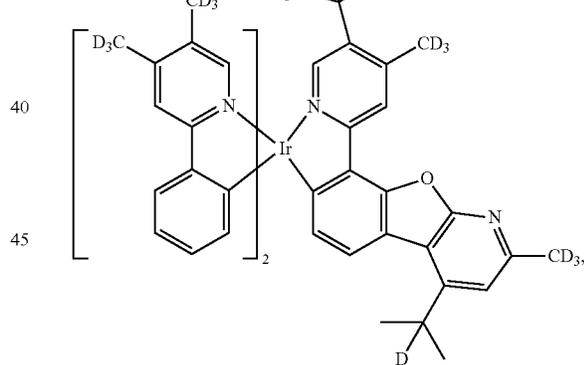
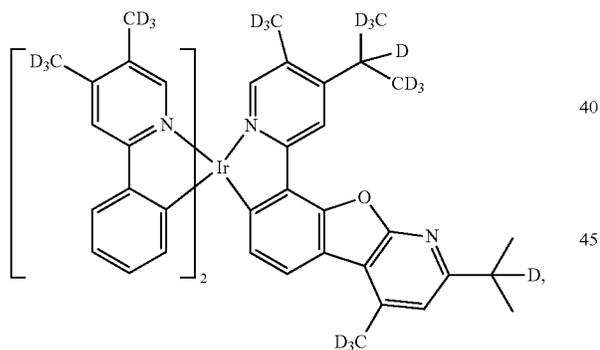
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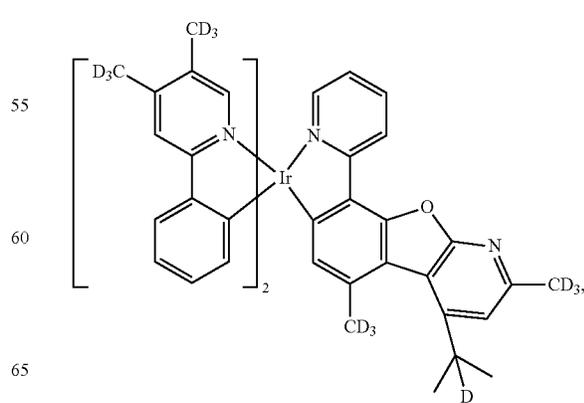
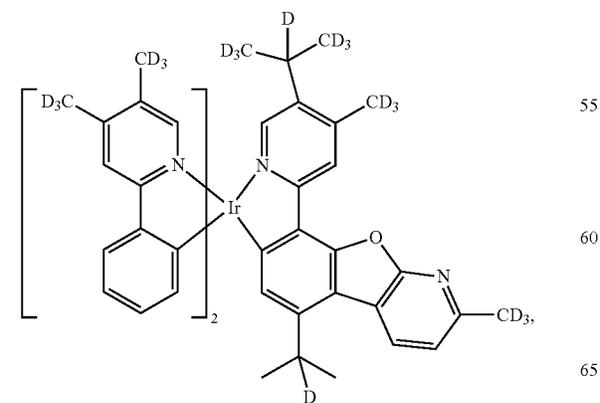


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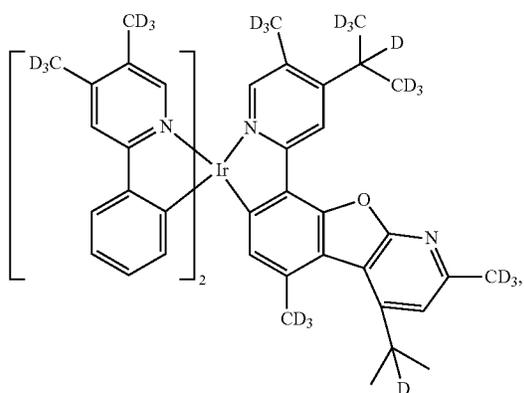
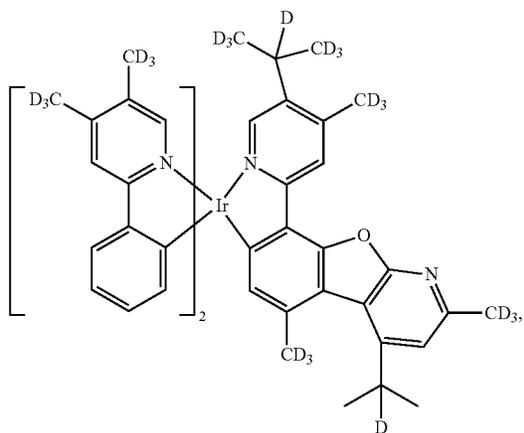
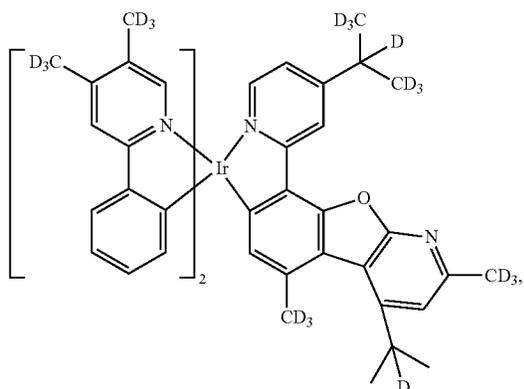


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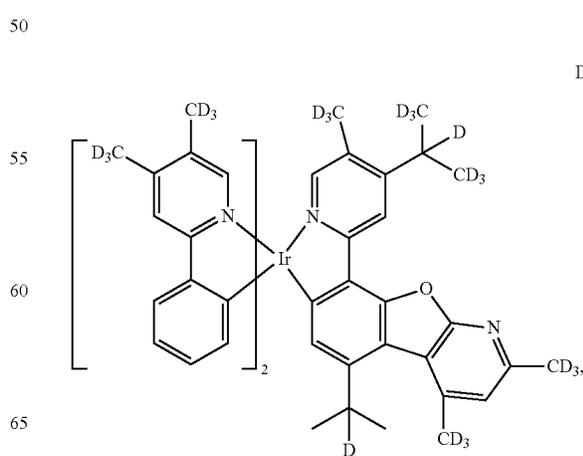
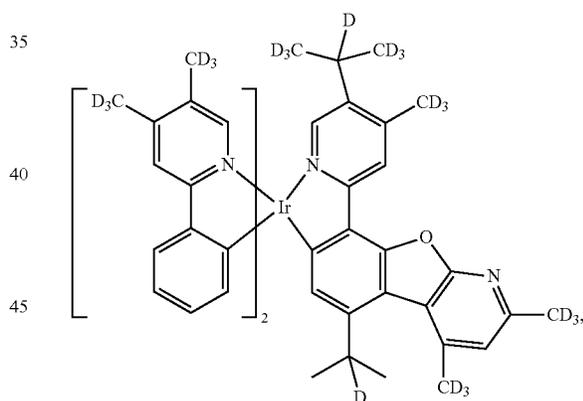
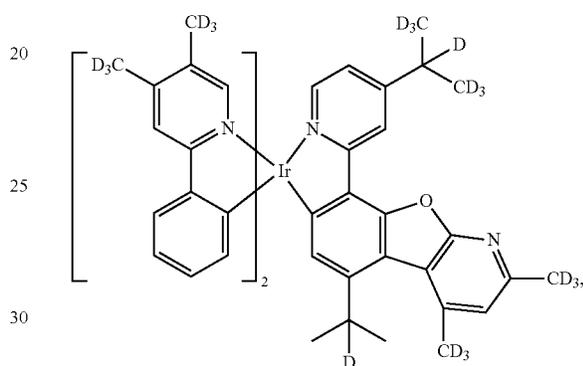
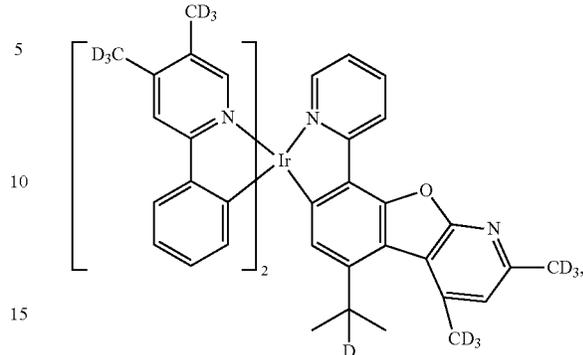


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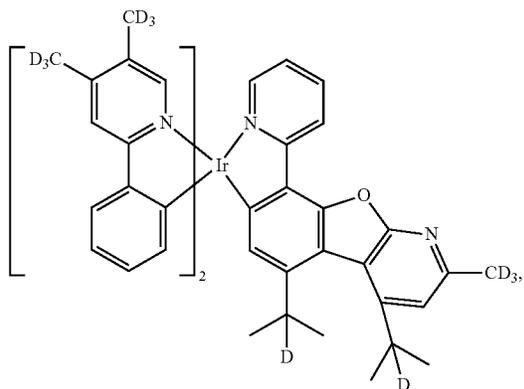
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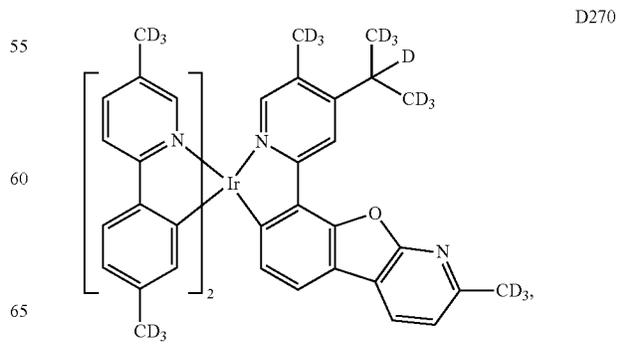
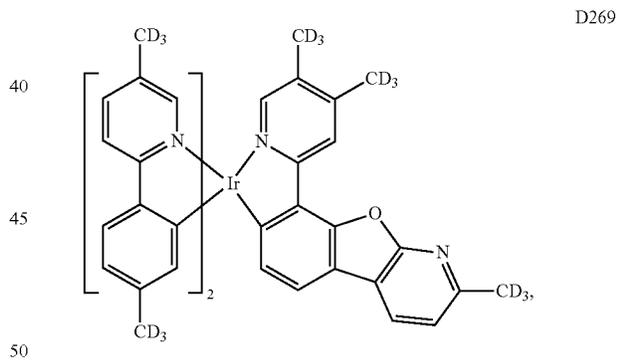
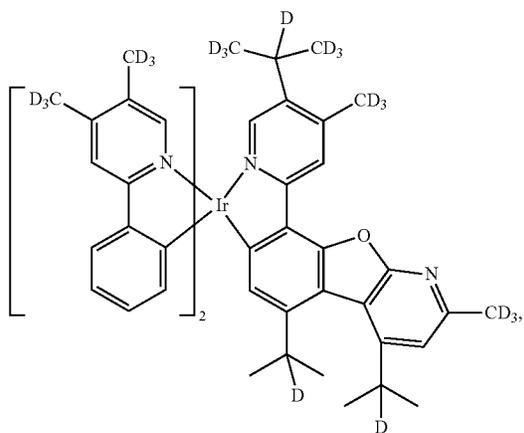
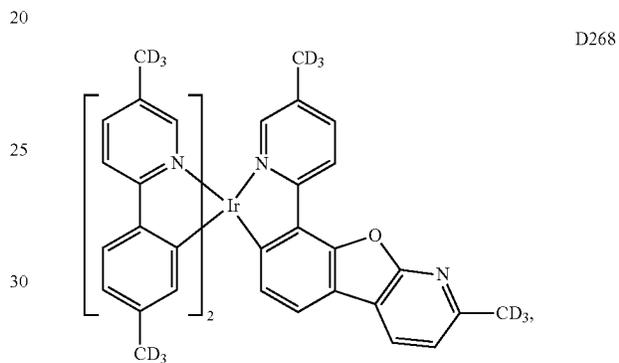
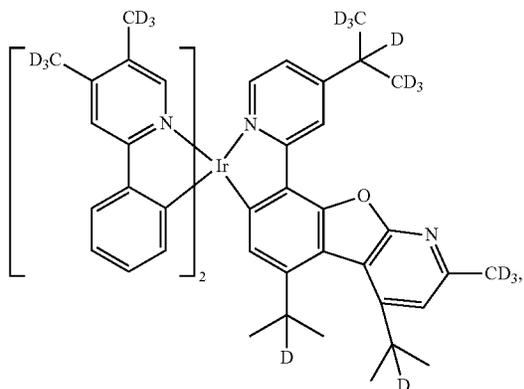
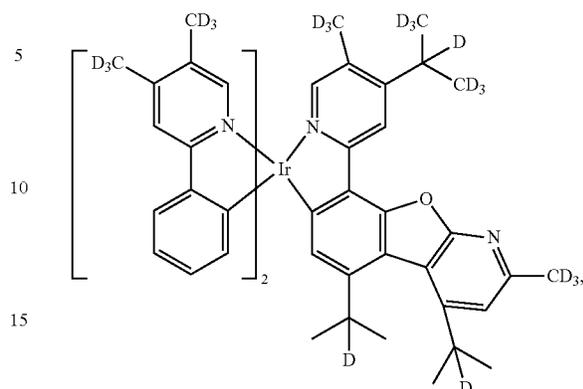
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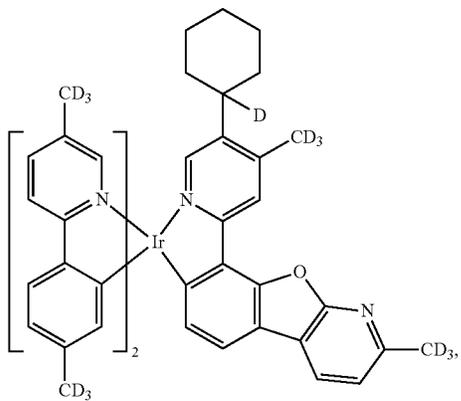
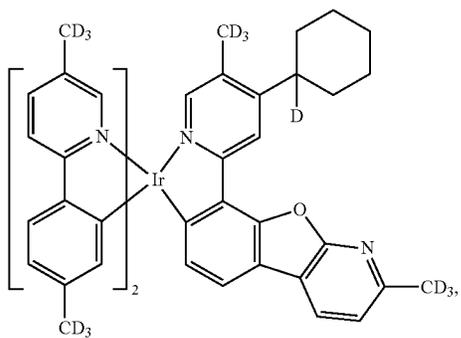
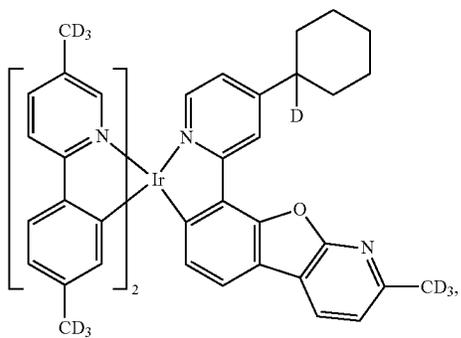
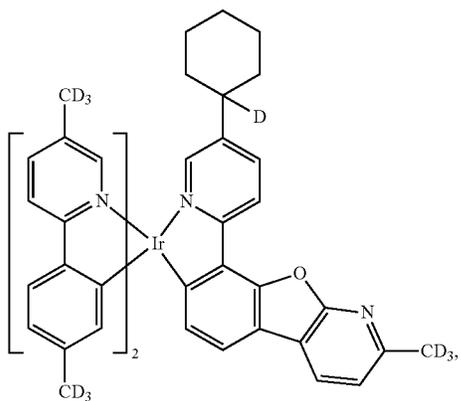


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**131**

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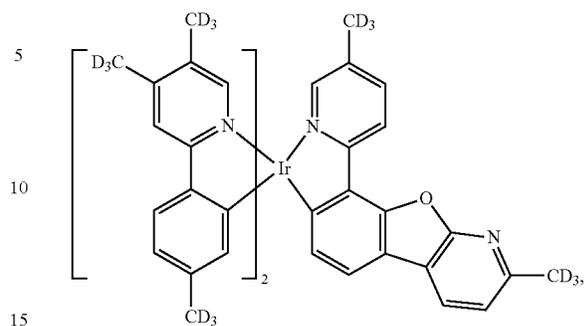


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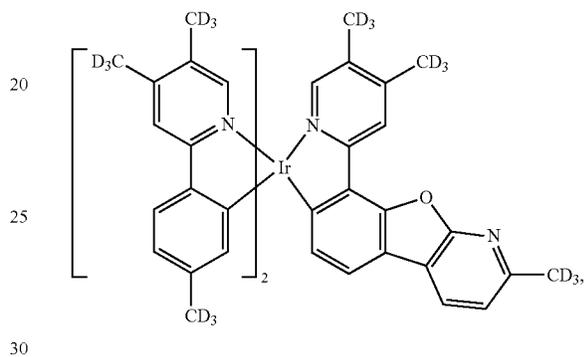
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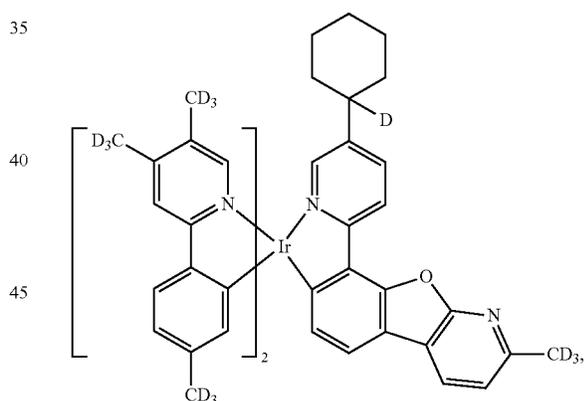
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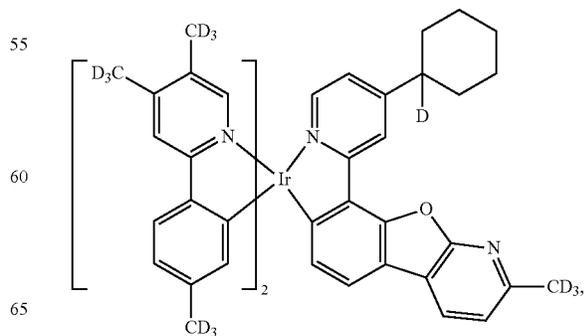
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D273



D274

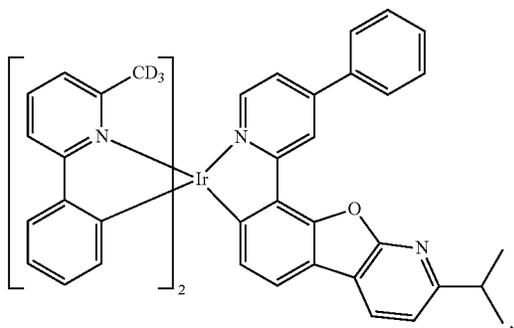
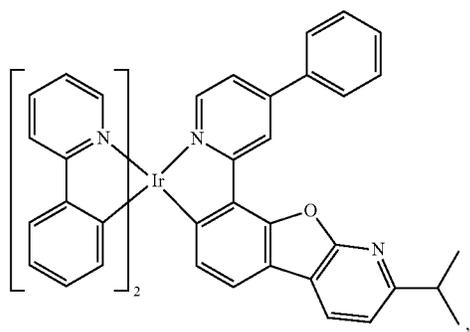
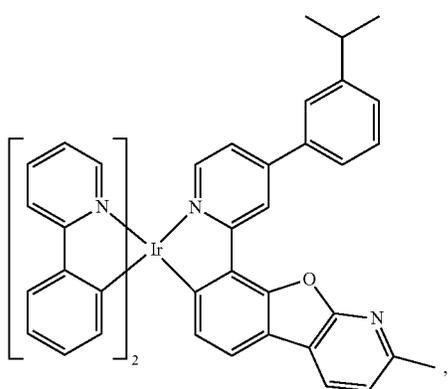
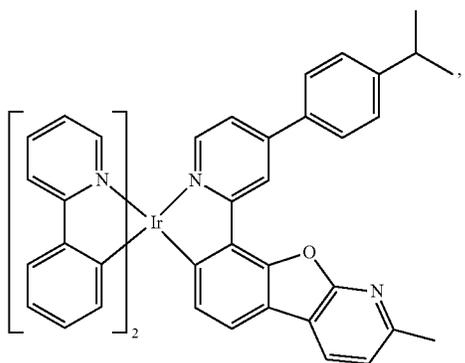


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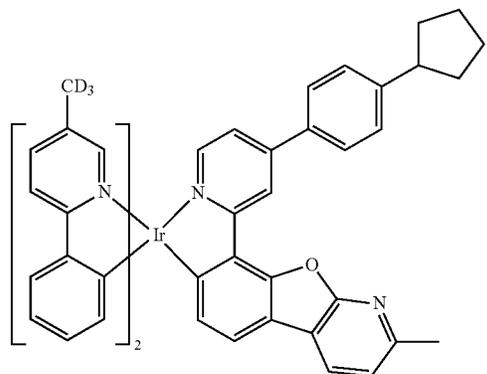
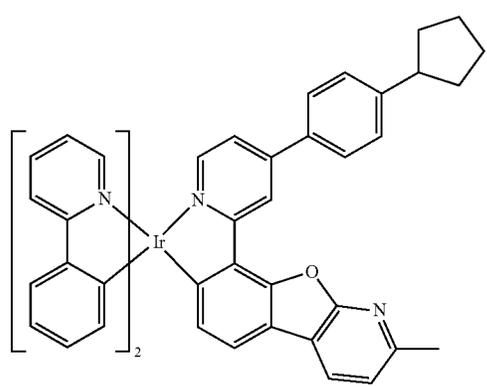
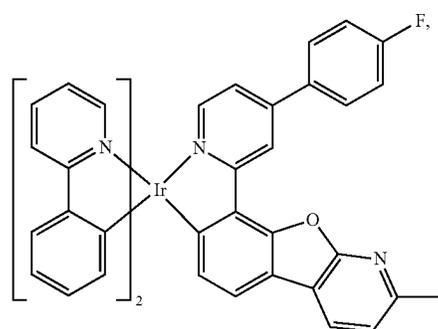
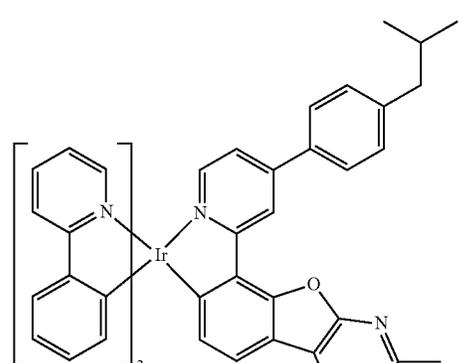
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D278

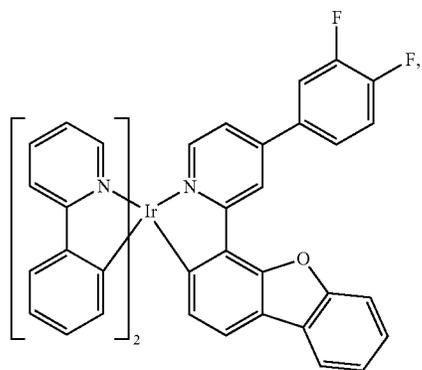
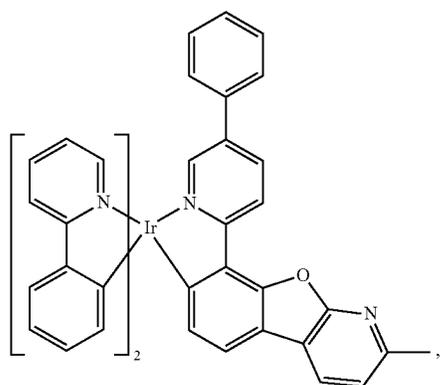
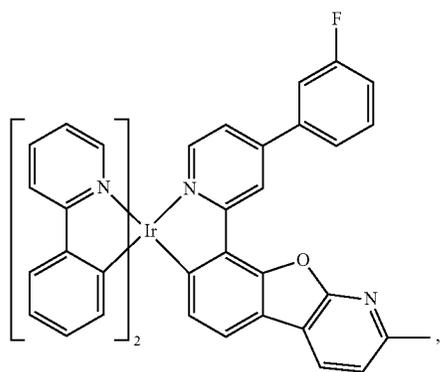
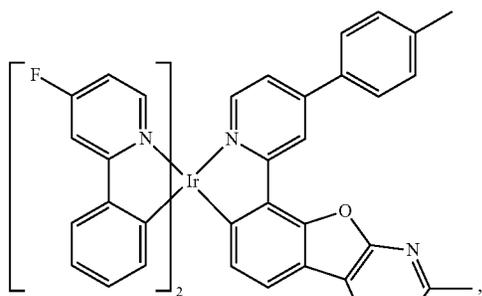
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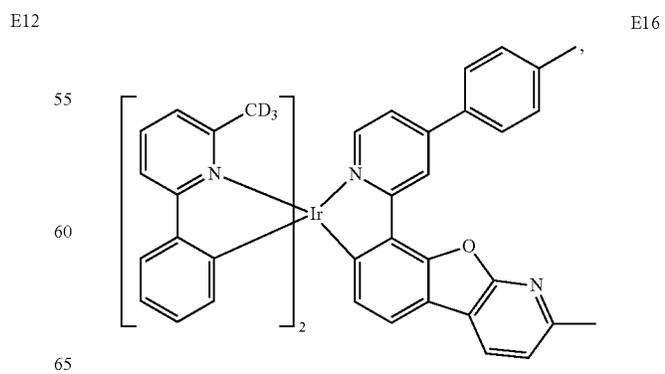
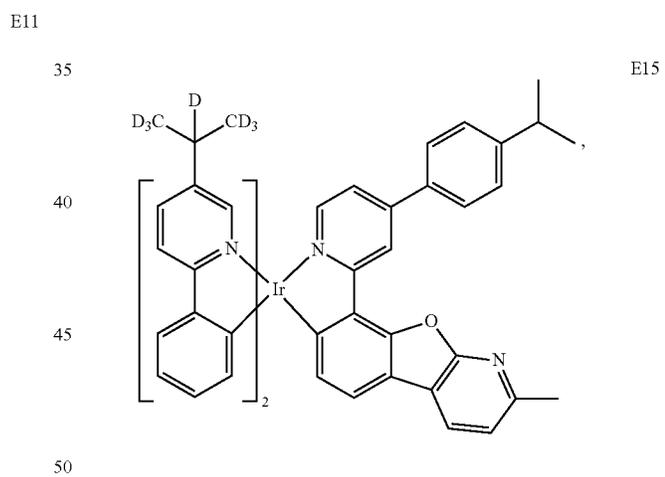
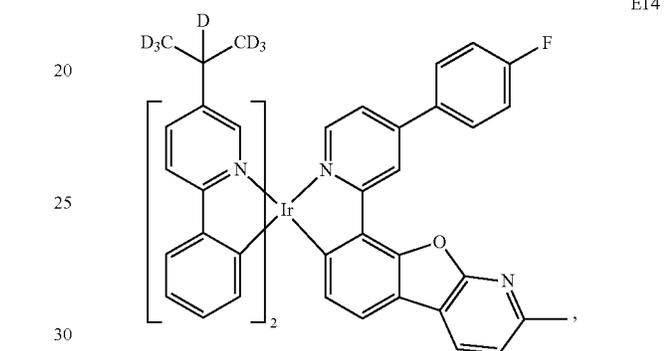
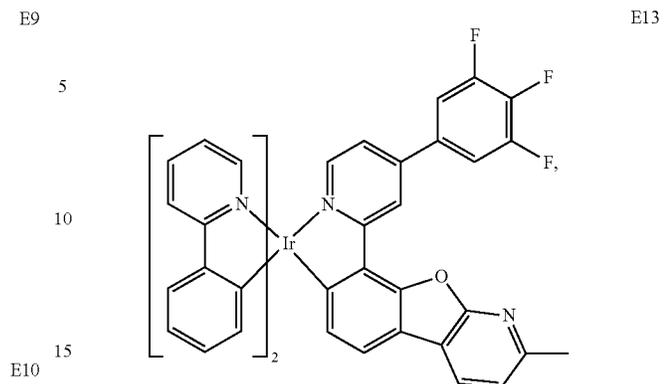
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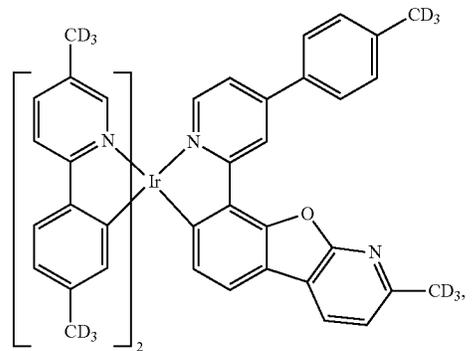
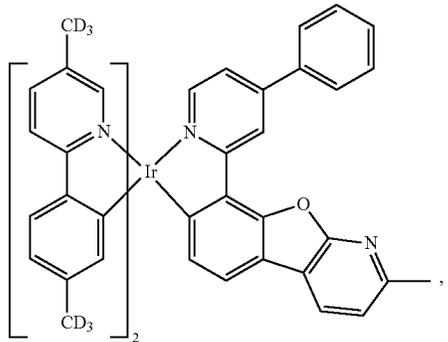
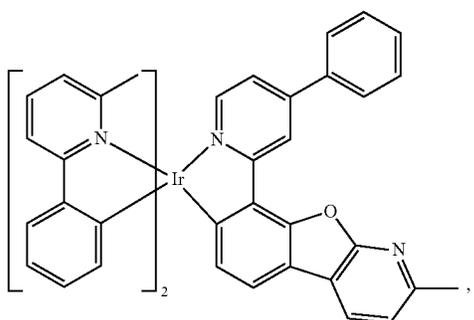
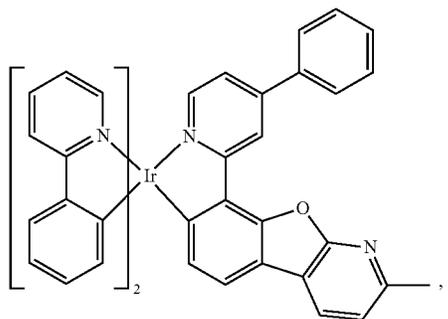
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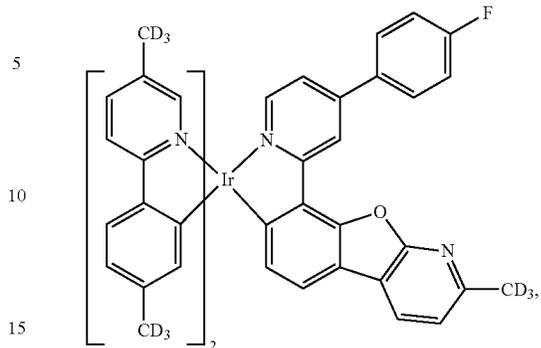


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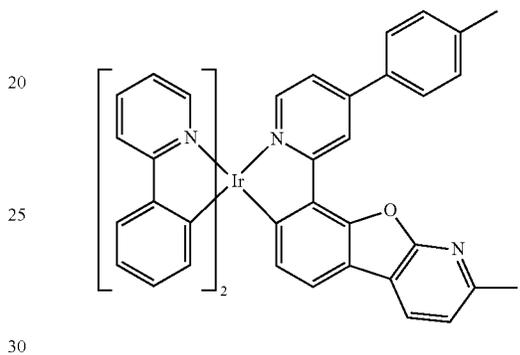
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E17



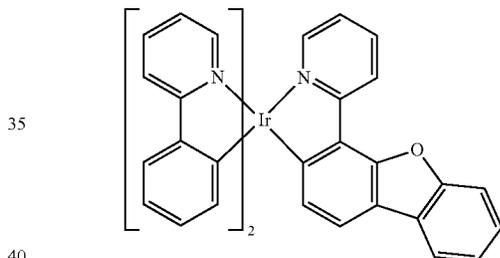
E21

E18



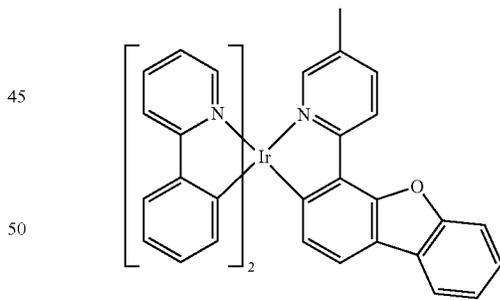
E19

E19



F1

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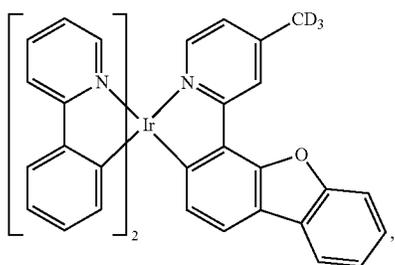
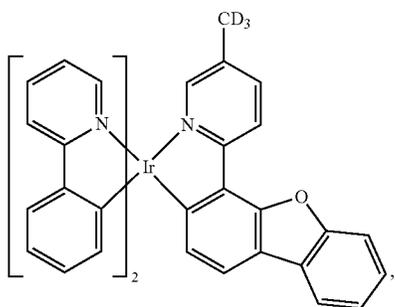
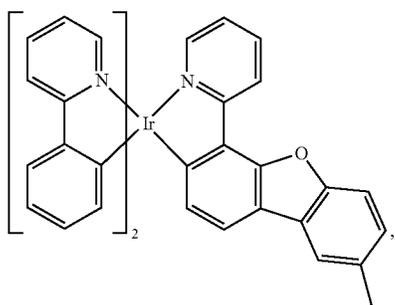
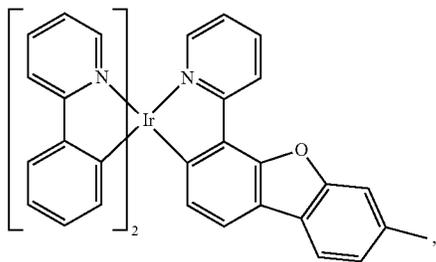
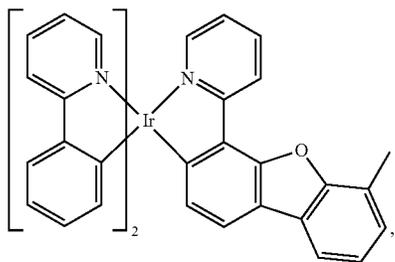
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F3

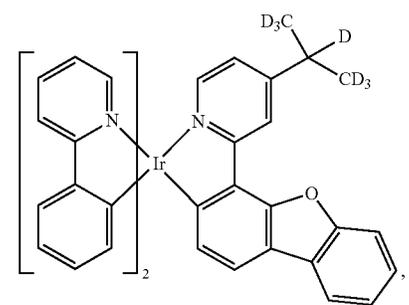
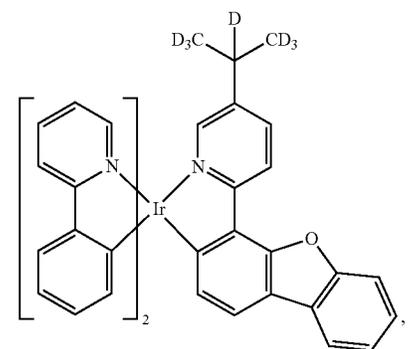
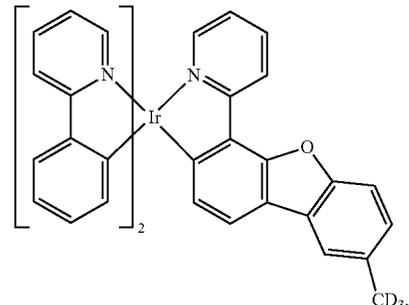
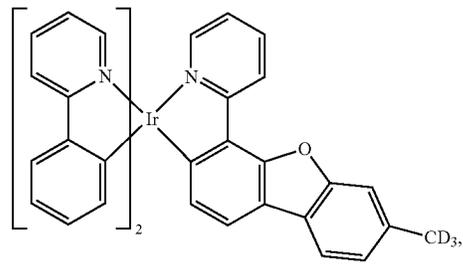
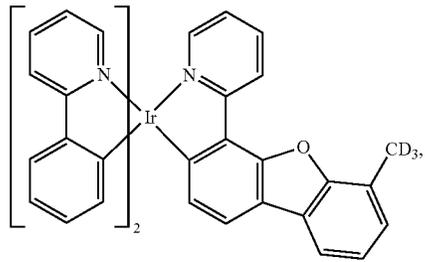
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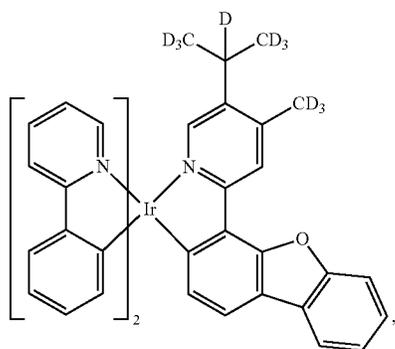
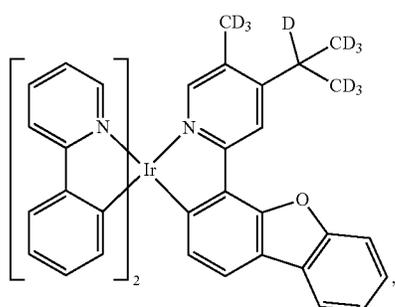
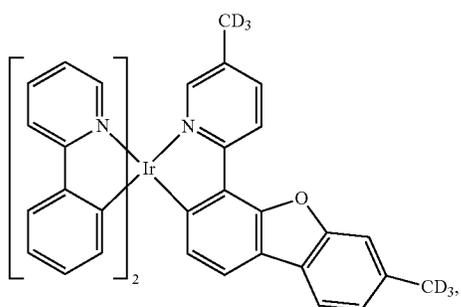
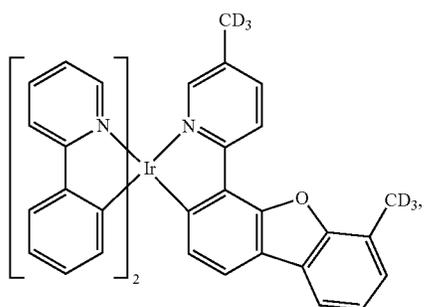
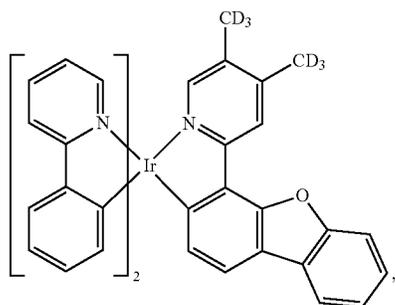


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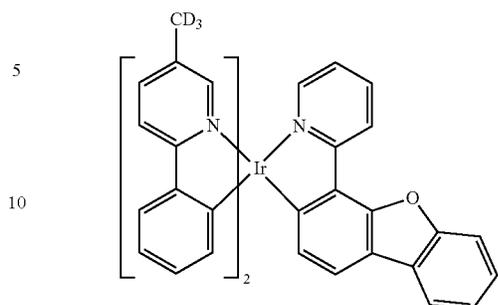


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**142**  
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F14

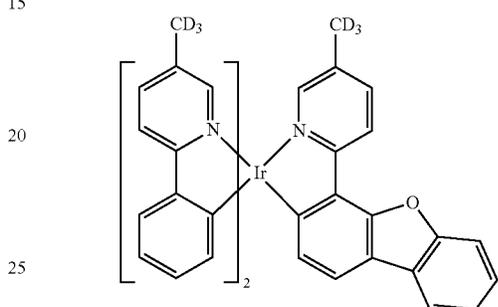


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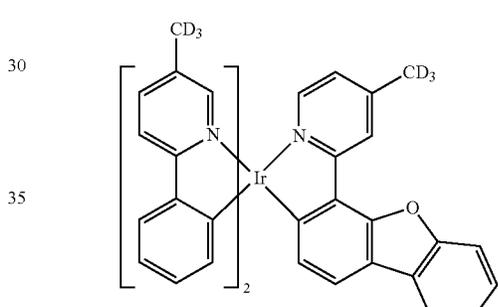


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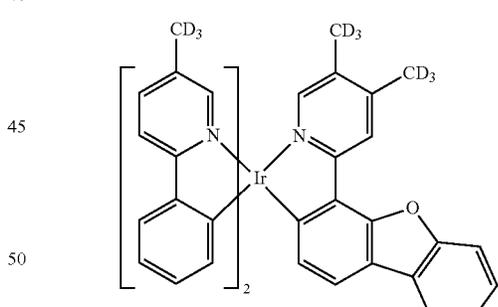


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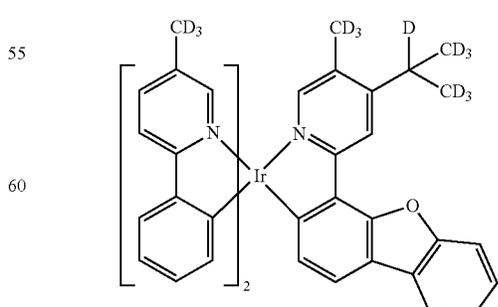


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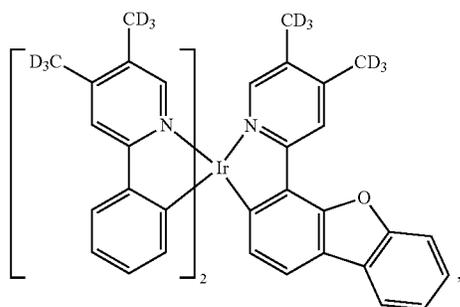
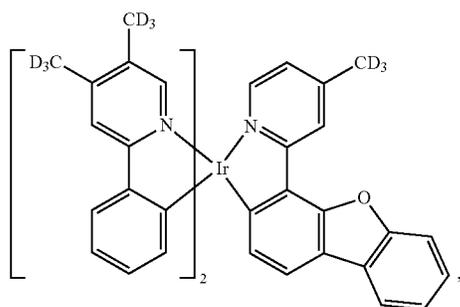
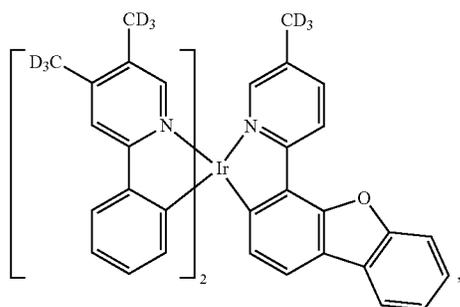
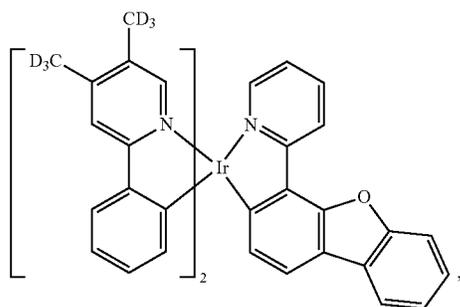
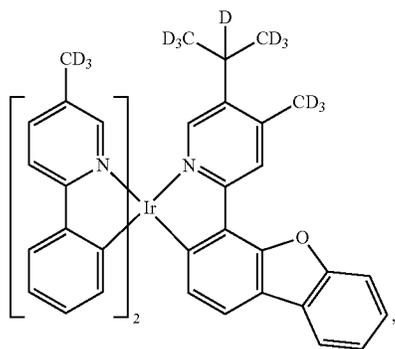
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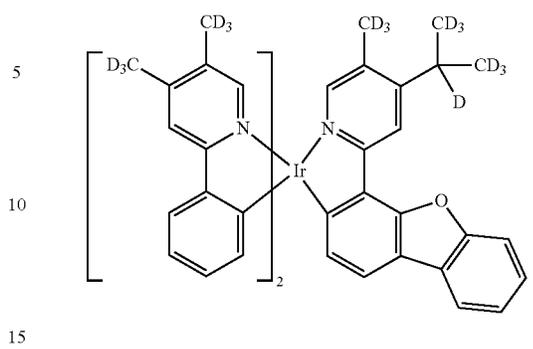
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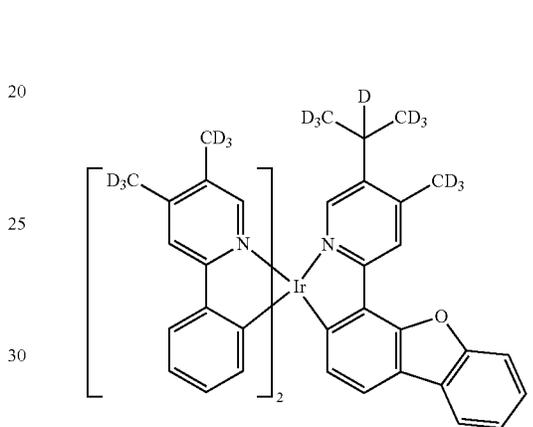
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F24



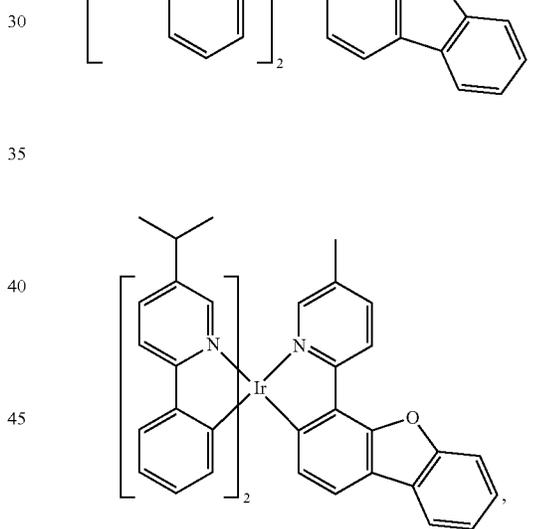
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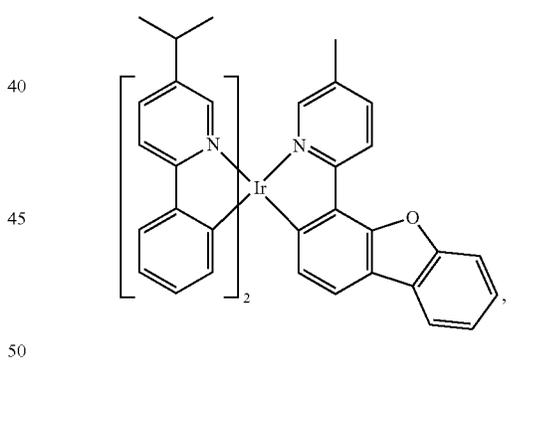
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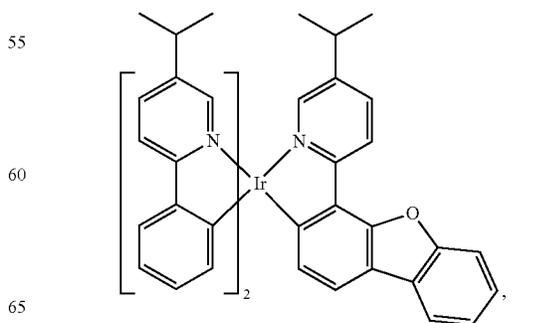


F31

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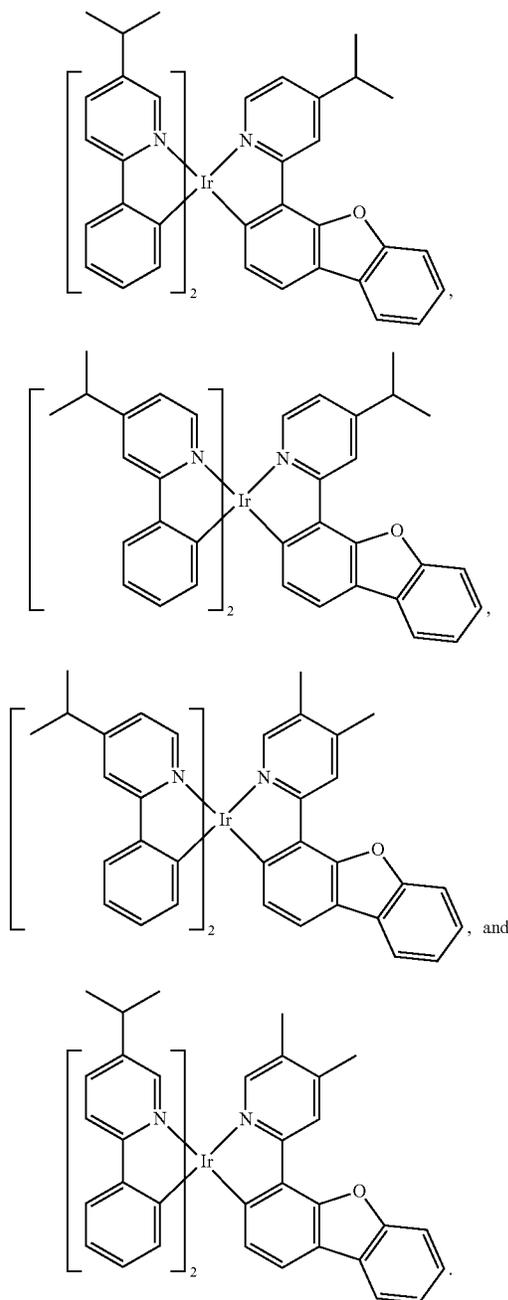
F28



F32

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In some embodiments of the composition of material, the mixture of the first compound and the second compound is selected from the group consisting of (Compound A1, Compound D1), (Compound A1, Compound D3), (Compound A1, Compound D4), (Compound A1, Compound D6), (Compound A1, Compound D11), (Compound A1, Compound D12), (Compound A1, Compound D13), (Compound A1, Compound D17), (Compound A1, Compound D18), (Compound A1, Compound D19), (Compound A1, Compound D23), (Compound A1, Compound D28), (Compound A1, Compound D29), (Compound A1, Compound D85), (Compound A1, Compound D87), (Compound A1, Compound D154), (Compound A1, Compound D162), (Compound A1, Compound E3), (Compound A1, Compound

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:E6), (Compound A1, Compound E8), (Compound A1, Compound E15), (Compound A1, Compound F10), (Compound A1, Compound F12), (Compound A1, Compound F27), (Compound A1, Compound F36), (Compound A3, Compound D1), (Compound A4, Compound D3), (Compound A5, Compound D4), (Compound A6, Compound D6), (Compound A7, Compound D11), (Compound A12, Compound D12), (Compound A3, Compound D13), (Compound A4, Compound D13), (Compound A5, Compound D13), (Compound A6, Compound D13), (Compound A7, Compound D13), (Compound B21, Compound D13), (Compound B25, Compound D13), (Compound C2, Compound D18), (Compound C3, Compound D19), (Compound C4, Compound D23), (Compound HA20, Compound D13), (Compound HA21, Compound D85), (Compound HA26, Compound D151), (Compound HA30, Compound 87), (Compound HA31, Compound D26), (Compound HA33, Compound D13), (Compound HA34, Compound D85), (Compound HA38, Compound D28), (Compound HA47, Compound D162), (Compound HA52, Compound D85), (Compound HA68, Compound D151), (Compound HA90, Compound D13), (Compound HA91, Compound D6), (Compound HA92, Compound D154) and Compound HA93, Compound E15).

In some embodiments of the mixture comprising a first compound and a second compound, the first compound has an evaporation temperature T1 of 150 to 350° C.; wherein the second compound has an evaporation temperature T2 of 150 to 350° C.; wherein absolute value of T1-T2 is less than 20° C.; wherein the first compound has a concentration C1 in said mixture and a concentration C2 in a film formed by evaporating the mixture in a vacuum deposition tool at a constant pressure between  $1 \times 10^{-6}$  Torr to  $1 \times 10^{-9}$  Torr, at a 2 Å/sec deposition rate on a surface positioned at a predefined distance away from the mixture being evaporated; and wherein absolute value of  $(C1-C2)/C1$  is less than 5%.

In some embodiments of the mixture, the first compound has a vapor pressure of P1 at T1 at 1 atm, the second compound has a vapor pressure of P2 at T2 at 1 atm; and wherein the ratio of P1/P2 is within the range of 0.90 to 1.10.

In some embodiments of the mixture, the first compound has a first mass loss rate and the second compound has a second mass loss rate, wherein the ratio between the first mass loss rate and the second mass loss rate is within the range of 0.90 to 1.10.

In some embodiments of the mixture, the first compound and the second compound each has a purity in excess of 99% as determined by high pressure liquid chromatography.

In some embodiments, the mixture further comprises a third compound, wherein the third compound has a different chemical structure than the first and second compounds, wherein the third compound has an evaporation temperature T3 of 150 to 350° C., and wherein absolute value of T1-T3 is less than 20° C.

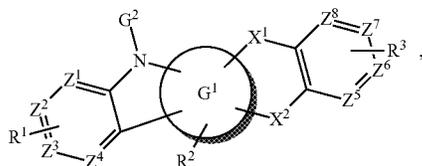
In some embodiments, the mixture further comprises a third compound, wherein the third compound has a different chemical structure than the first and second compounds, wherein the third compound has a third mass loss rate and the ratio between the first mass loss rate and third mass loss rate is within the range of 0.90 to 1.10.

In some embodiments, the composition of material comprising the mixture is in liquid form at a temperature less than T1 and T2.

According to another aspect of the present disclosure, an OLED is disclosed, wherein the OLED comprises an anode; a cathode; and an organic layer disposed between the anode and the cathode. The organic layer comprises a composition

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of material comprising a mixture of a first compound and a second compound, wherein the first compound has the structure of Formula I



wherein  $G^1$  is a six-member aromatic ring;

wherein  $X^1$  and  $X^2$  are each independently selected from the group consisting of direct bond,  $CR^4R^5$ ,  $NR^6$ , O, S and Se;

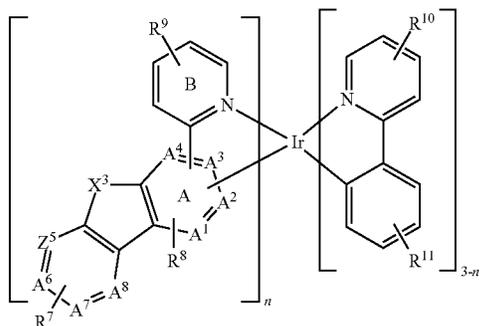
wherein at least one of  $X^1$  and  $X^2$  is not a direct bond;

wherein  $Z^1$  to  $Z^8$  are each independently selected from the group consisting of nitrogen and carbon;

wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $G^2$ ,  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$  and  $R^6$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein any two adjacent substituents can optionally join or fuse into a ring;

wherein the second compound has a formula  $Ir(L_A)_n(L_B)_{3-n}$ , and having a structure according to Formula II



wherein each  $A^1$ ,  $A^2$ ,  $A^3$ ,  $A^4$ ,  $A^5$ ,  $A^6$ ,  $A^7$ , and  $A^8$  comprise carbon or nitrogen;

wherein ring B is bonded to ring A through a C—C bond; wherein the iridium is bonded to ring A through a Ir—C bond;

wherein  $X^3$  is selected from a group consisting of O, S and Se;

wherein  $R^7$  to  $R^{11}$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $R^7$  to  $R^{11}$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and wherein any two adjacent

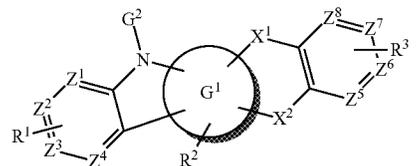
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substituents can optionally join or fuse into a ring; and wherein  $n$  is an integer from 1 to 3.

In some embodiments of the OLED, the organic layer is an emissive layer. In some embodiments of the OLED, the OLED is incorporated into a device selected from the group consisting of a consumer product, an electronic component module, and a lighting panel.

According to another aspect of the present disclosure, a method for fabricating an organic light emitting device is disclosed. The method comprising: providing a substrate having a first electrode disposed thereon; depositing a first organic layer over the first electrode by evaporating a mixture of a first compound and a second compound in a vacuum deposition tool at a constant pressure between  $1 \times 10^{-6}$  Torr to  $1 \times 10^{-9}$  Torr, at a  $2 \text{ \AA}/\text{sec}$  deposition rate on a surface position at a predefined distance away from the mixture being evaporated; and depositing a second electrode over the first organic layer;

wherein the first compound has the structure of Formula I



wherein  $G^1$  is a six-member aromatic ring;

wherein  $X^1$  and  $X^2$  are each independently selected from the group consisting of direct bond,  $CR^4R^5$ ,  $NR^6$ , O, S and Se;

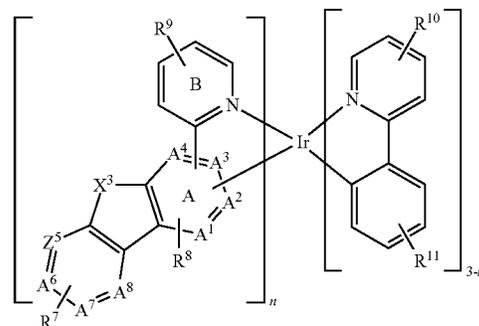
wherein at least one of  $X^1$  and  $X^2$  is not a direct bond;

wherein  $Z^1$  to  $Z^8$  are each independently selected from the group consisting of nitrogen and carbon;

wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $G^2$ ,  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$  and  $R^6$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein any two adjacent substituents can optionally join or fuse into a ring;

wherein the second compound has a formula  $Ir(L_A)_n(L_B)_{3-n}$ , and having a structure according to Formula II



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wherein each  $A^1$ ,  $A^2$ ,  $A^3$ ,  $A^4$ ,  $A^5$ ,  $A^6$ ,  $A^7$ , and  $A^8$  comprise carbon or nitrogen;

wherein ring B is bonded to ring A through a C—C bond;

wherein the iridium is bonded to ring A through a Ir—C bond;

wherein  $X^3$  is selected from a group consisting of O, S and Se;

wherein  $R^7$  to  $R^{11}$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $R^7$  to  $R^{11}$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfonyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and

wherein any two adjacent substituents can optionally join or fuse into a ring; and

wherein n is an integer from 1 to 3.

#### Combination with Other Materials

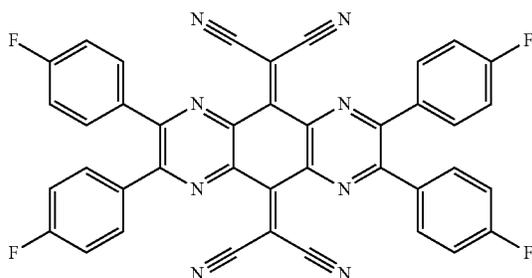
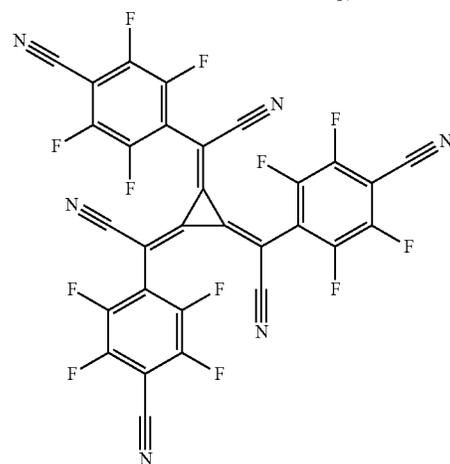
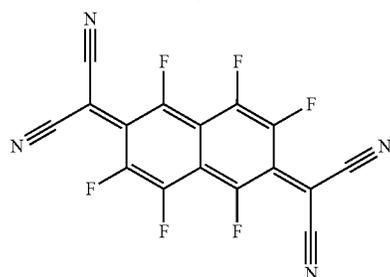
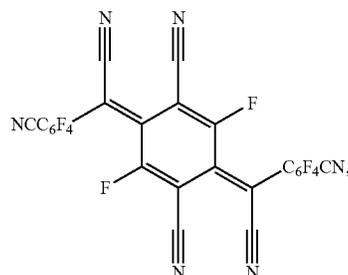
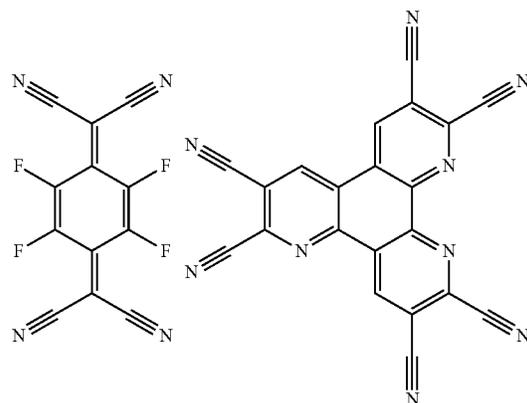
The materials described herein as useful for a particular layer in an organic light emitting device may be used in combination with a wide variety of other materials present in the device. For example, emissive dopants disclosed herein may be used in conjunction with a wide variety of hosts, transport layers, blocking layers, injection layers, electrodes and other layers that may be present. The materials described or referred to below are non-limiting examples of materials that may be useful in combination with the compounds disclosed herein, and one of skill in the art can readily consult the literature to identify other materials that may be useful in combination.

#### Conductivity Dopants:

A charge transport layer can be doped with conductivity dopants to substantially alter its density of charge carriers, which will in turn alter its conductivity. The conductivity is increased by generating charge carriers in the matrix material, and depending on the type of dopant, a change in the Fermi level of the semiconductor may also be achieved. Hole-transporting layer can be doped by p-type conductivity dopants and n-type conductivity dopants are used in the electron-transporting layer.

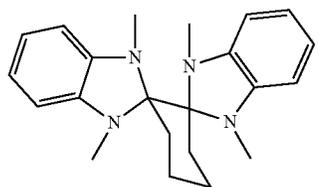
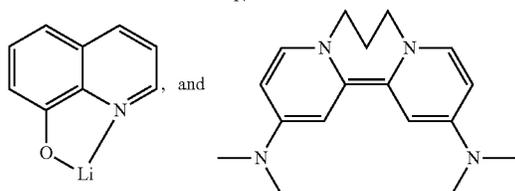
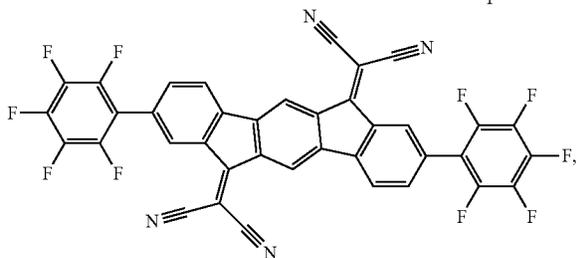
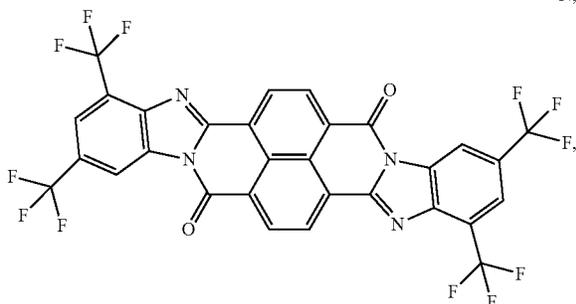
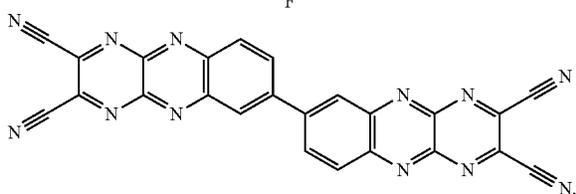
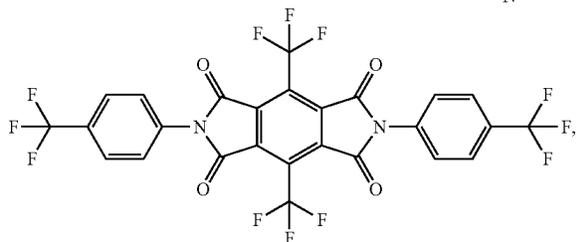
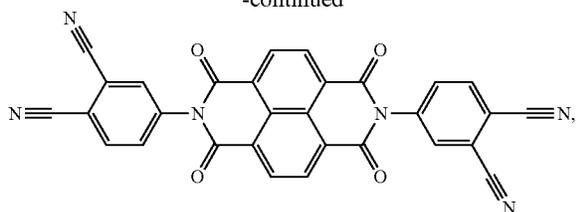
Non-limiting examples of the conductivity dopants that may be used in an OLED in combination with materials disclosed herein are exemplified below together with references that disclose those materials: EP01617493, EP01968131, EP2020694, EP2684932, US20050139810, 0820070160905, US20090167167, US2010288362, WO06081780, WO2009003455, WO2009008277, WO2009011327, WO2014009310, US2007252140, US2015060804 and US2012146012.

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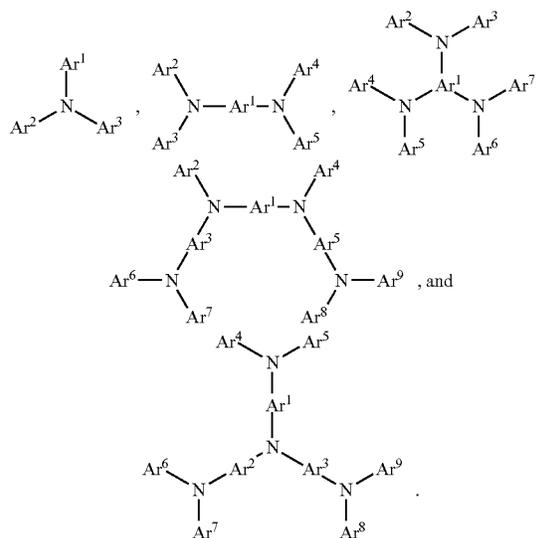


A hole injecting/transporting material to be used in the present invention is not particularly limited, and any compound may be used as long as the compound is typically used as a hole injecting/transporting material. Examples of

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the material include, but are not limited to: a phthalocyanine or porphyrin derivative; an aromatic amine derivative; an indolocarbazole derivative; a polymer containing fluorohydrocarbon; a polymer with conductivity dopants; a conducting polymer, such as PEDOT/PSS; a self-assembly monomer derived from compounds such as phosphonic acid and silane derivatives; a metal oxide derivative, such as  $\text{MoO}_x$ ; a p-type semiconducting organic compound, such as 1,4,5,8,9,12-Hexaazatriphenylenehexacarbonitrile; a metal complex, and a cross-linkable compounds.

Examples of aromatic amine derivatives used in HIL or HTL include, but are not limited to the following general structures:

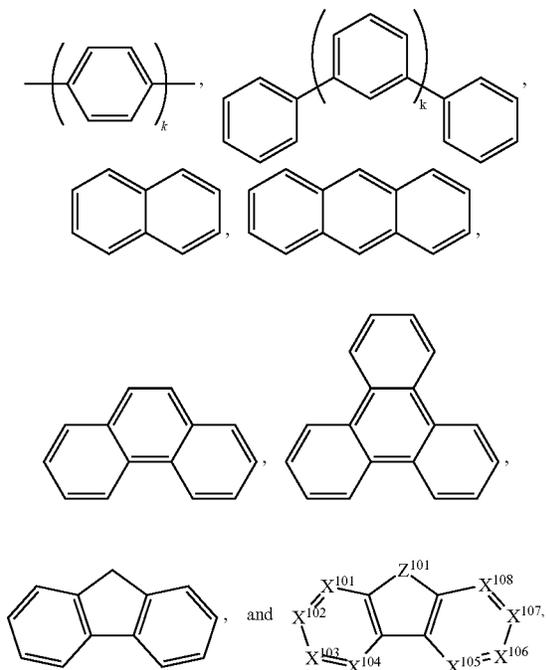


Each of  $\text{Ar}^1$  to  $\text{Ar}^9$  is selected from the group consisting of aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, and azulene; the group consisting of aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and the group consisting of 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atom, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Each Ar may be unsubstituted or may be substituted by a substituent selected from the group consisting of deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl,

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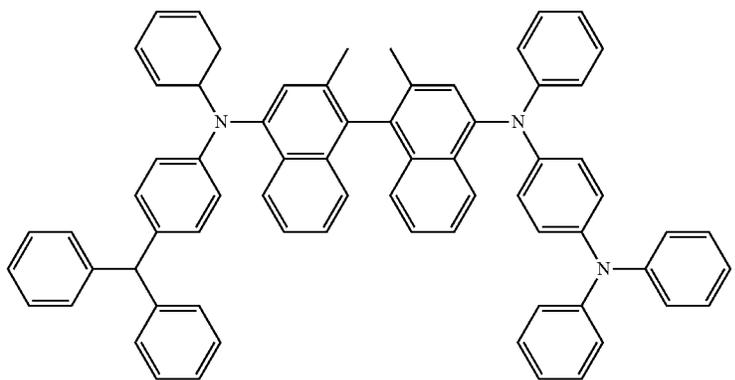
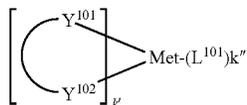
carboxylic acids, ester, nitrite, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, Ar<sup>1</sup> to Ar<sup>9</sup> is independently selected from the group consisting of:



wherein  $k$  is an integer from 1 to 20;  $X^{101}$  to  $X^{108}$  is C (including CH) or N;  $Z^{101}$  is NAr<sup>1</sup>, O, or S; Ar<sup>1</sup> has the same group defined above.

Examples of metal complexes used in Hit or HTL include, but are not limited to the following general formula:



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wherein Met is a metal, which can have an atomic weight greater than 40;  $(Y^{101}-Y^{102})$  is a bidentate ligand,  $Y^{101}$  and  $Y^{102}$  are independently selected from C, N, O, P, and S;  $L^{101}$  is an ancillary ligand;  $k'$  is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and  $k'+k''$  is the maximum number of ligands that may be attached to the metal.

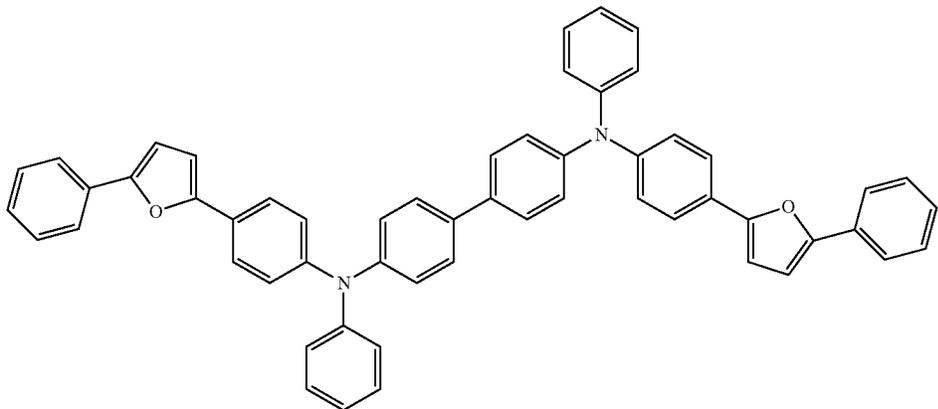
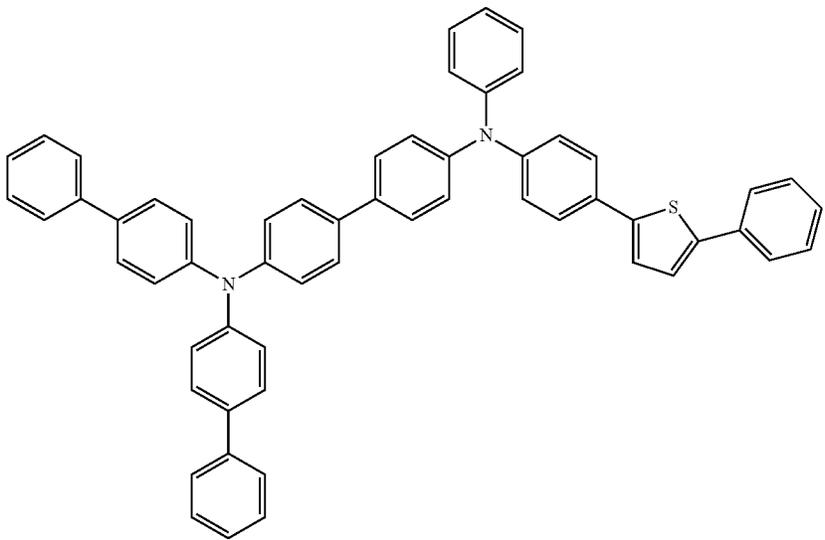
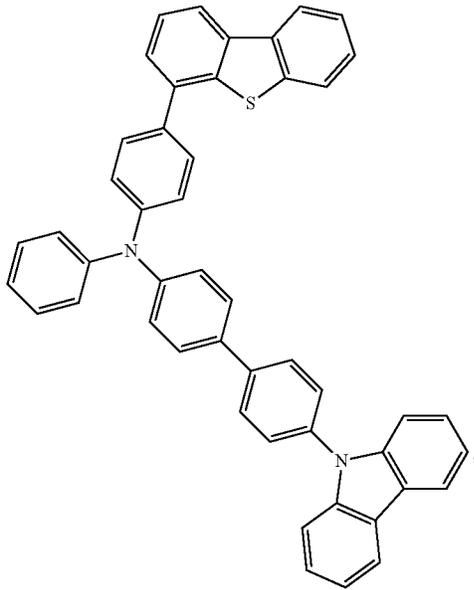
In one aspect,  $(Y^{101}-Y^{102})$  is a 2-phenylpyridine derivative. In another aspect,  $(Y^{101}-Y^{102})$  is a carbene ligand. In another aspect, Met is selected from Ir, Pt, Os, and Zn. In a further aspect, the metal complex has a smallest oxidation potential in solution vs.  $Fc^+/Fc$  couple less than about 0.6 V.

Non-limiting examples of the HIL and HTL materials that may be used in an OLED in combination with materials disclosed herein are exemplified below together with references that disclose those materials: CN102702075, DE102012005215, EP01624500, EP01698613, EP01806334, EP01930964, EP01972613, EP01997799, EP02011790, EP02055700, EP02055701, EP1725079, EP2085382, EP2660300, EP650955, JP07-073529, JP2005112765, JP2007091719, JP2008021687, JP2014-009196, KR20110088898, KR20130077473, TW201139402, US06517957, US20020158242, US20030162053, US20050123751, US20060182993, US20060240279, US20070145888, US20070181874, US20070278938, US20080014464, US20080091025, US20080106190, US20080124572, US20080145707, US20080220265, US20080233434, US20080303417, US2008107919, US20090115320, US20090167161, US2009066235, US2011007385, US20110163302, US2011240968, US2011278551, US2012205642, US2013241401, US20140117329, US2014183517, U.S. Pat. No. 5,061,569, U.S. Pat. No. 5,639,914, WO05075451, WO07125714, WO08023550, WO08023759, WO2009145016, WO2010061824, WO2011075644, WO2012177006, WO2013018530, WO2013039073, WO2013087142, WO2013118812, WO2013120577, WO2013157367, WO2013175747, WO2014002873, WO2014015935, WO2014015937, WO2014030872, WO2014030921, WO2014034791, WO2014104514, WO2014157018,

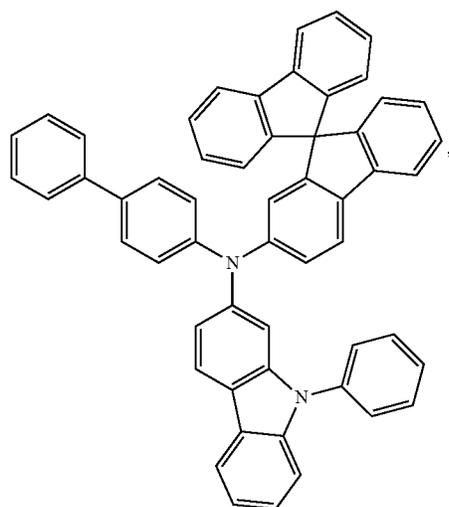
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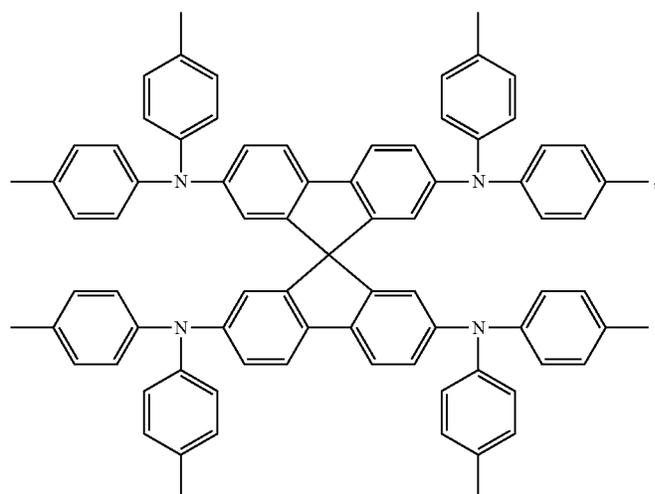
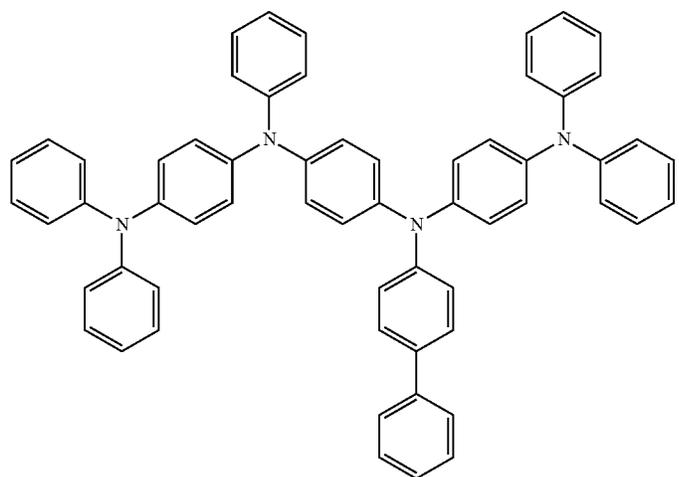
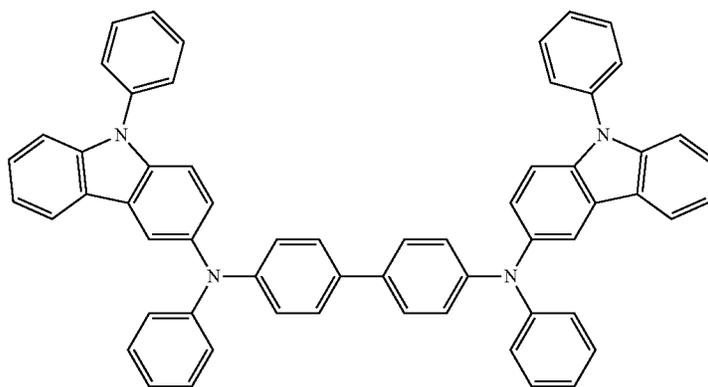


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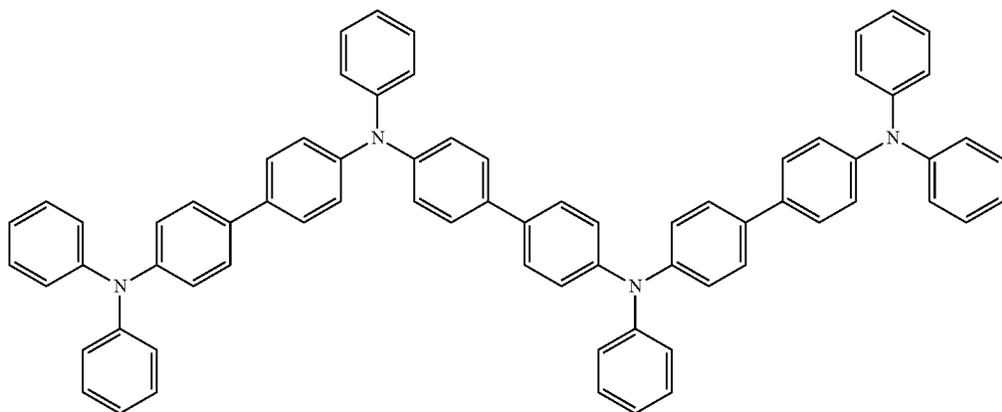
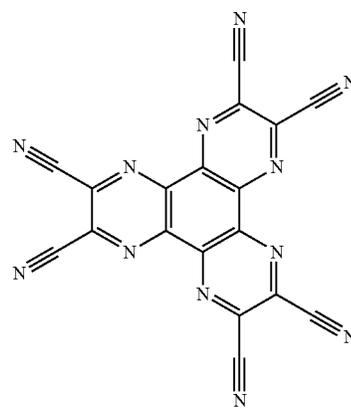
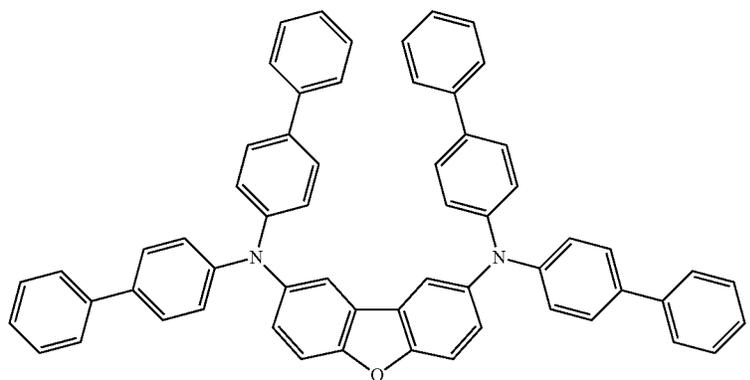
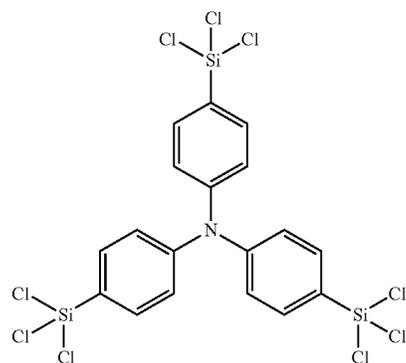
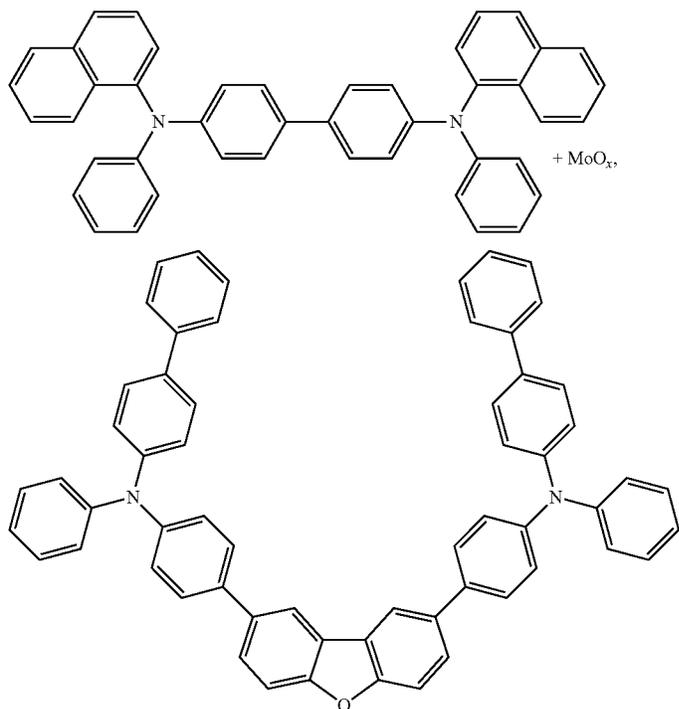




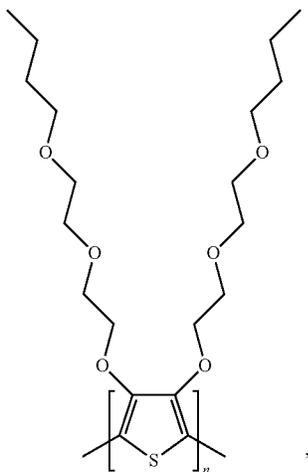
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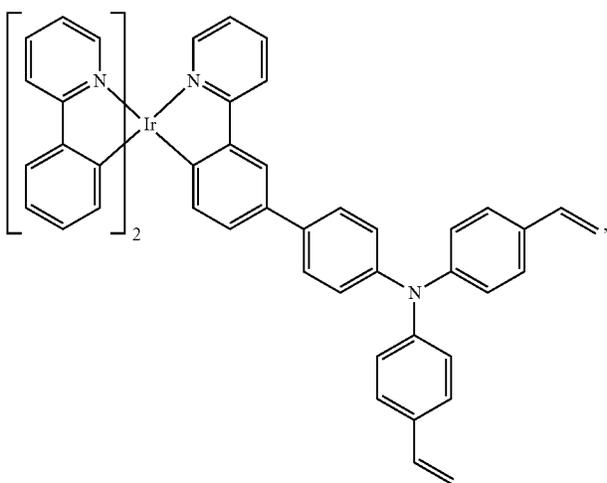
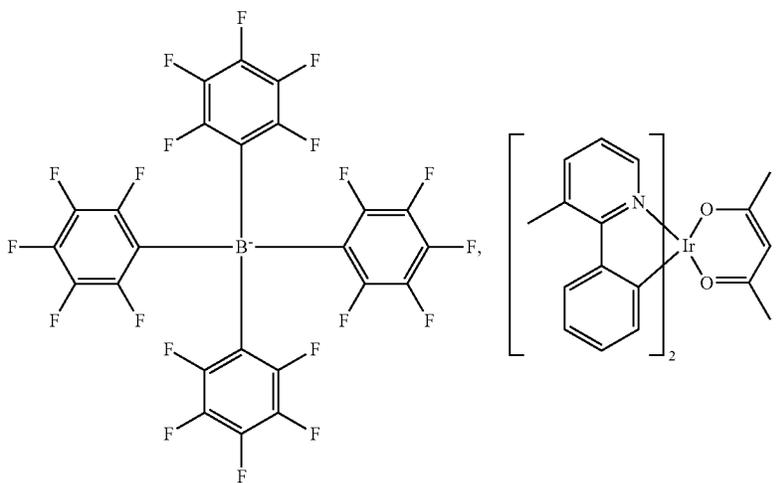
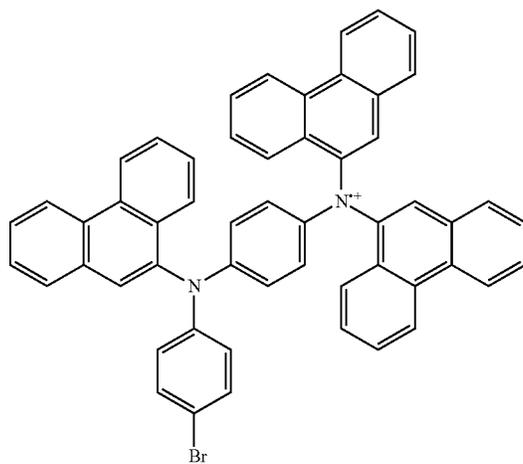


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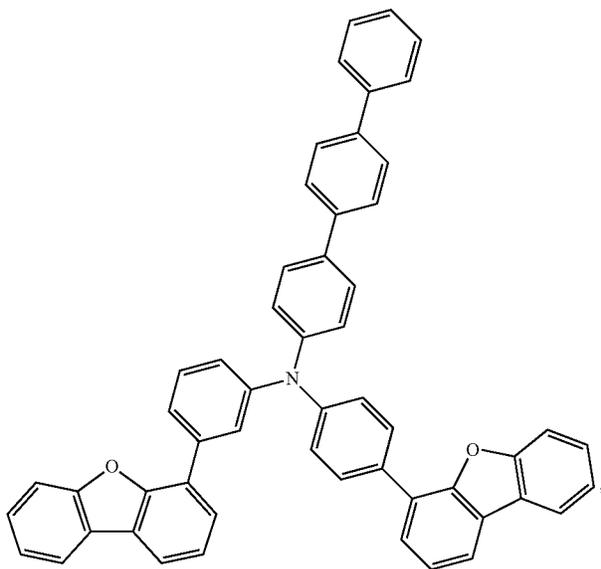
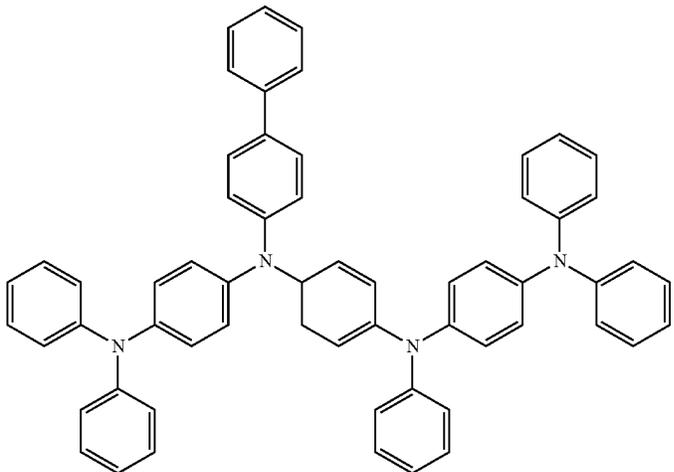
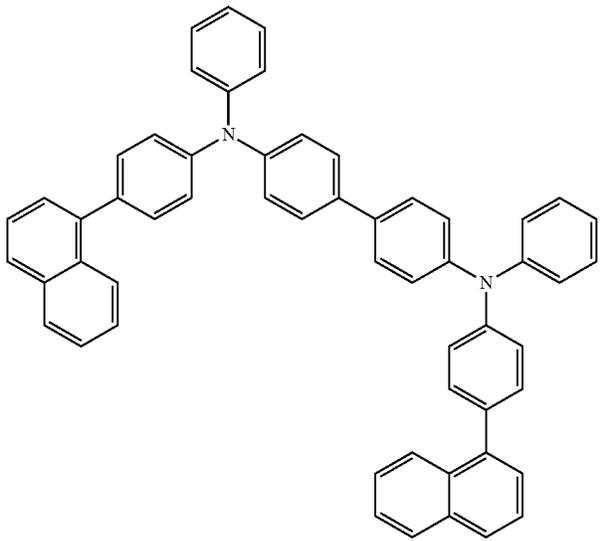
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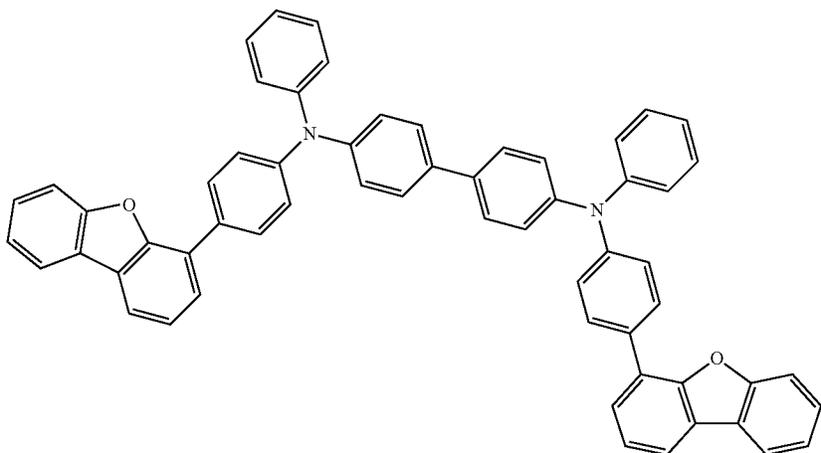
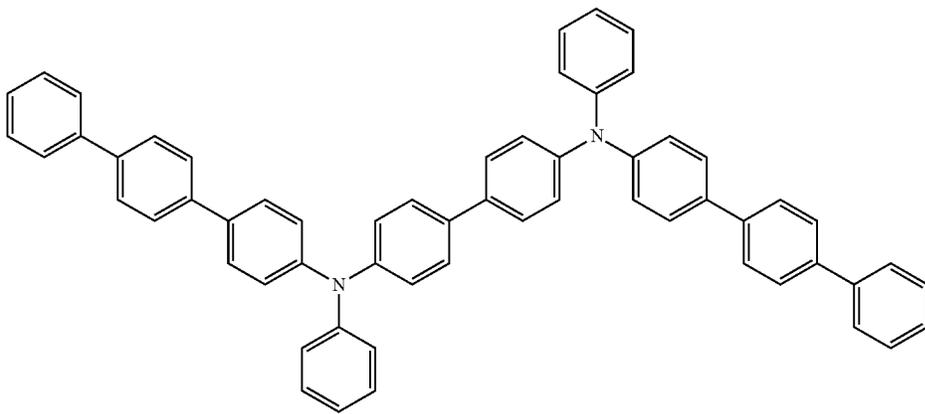
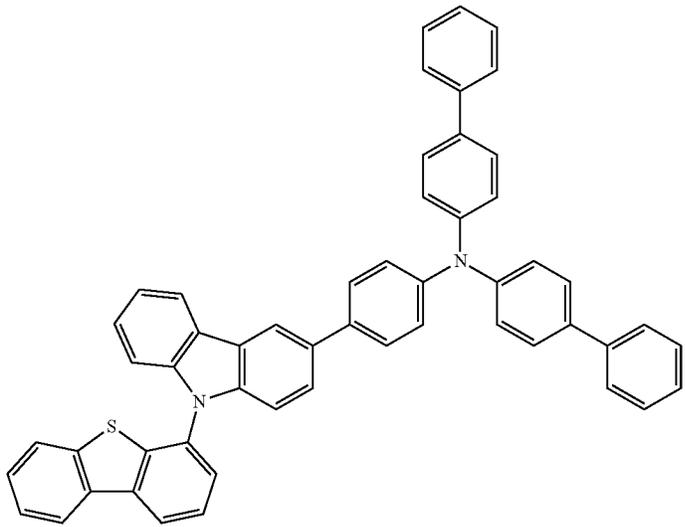
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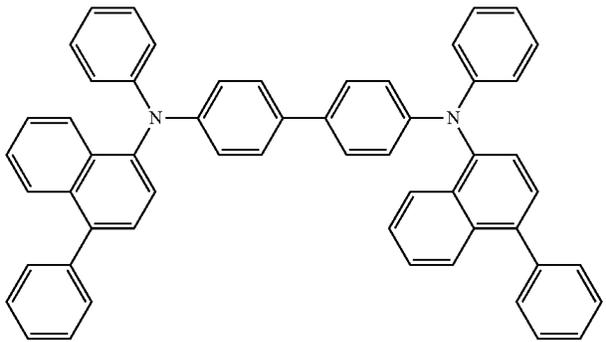
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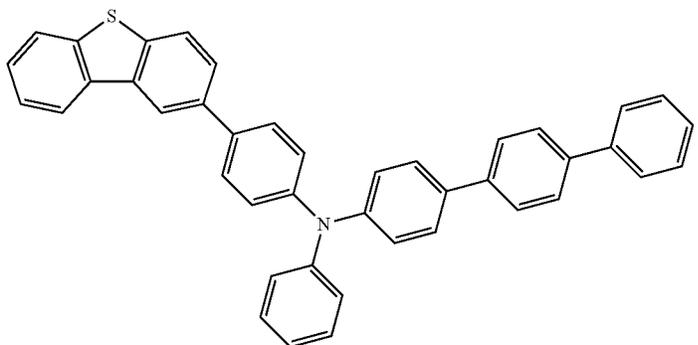
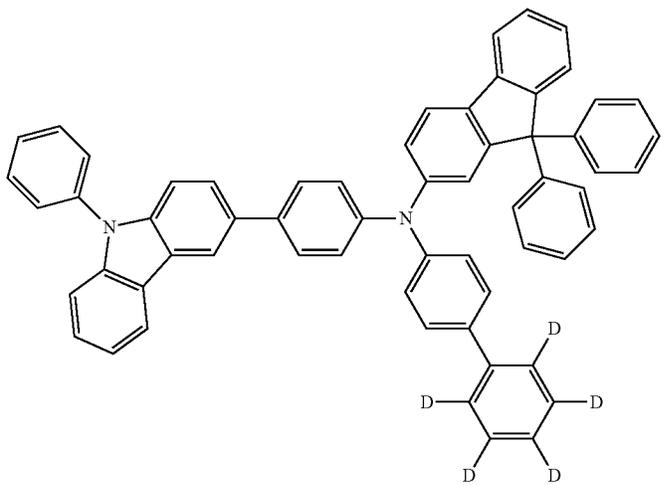
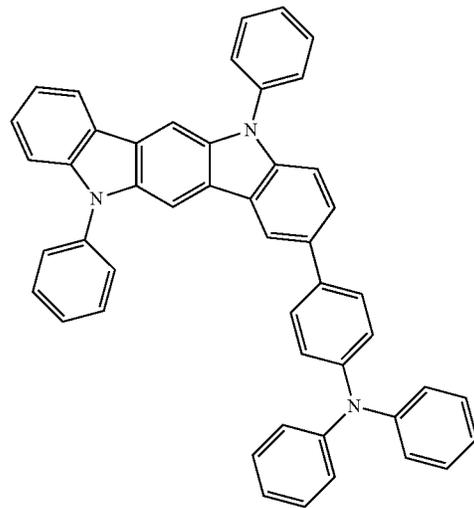
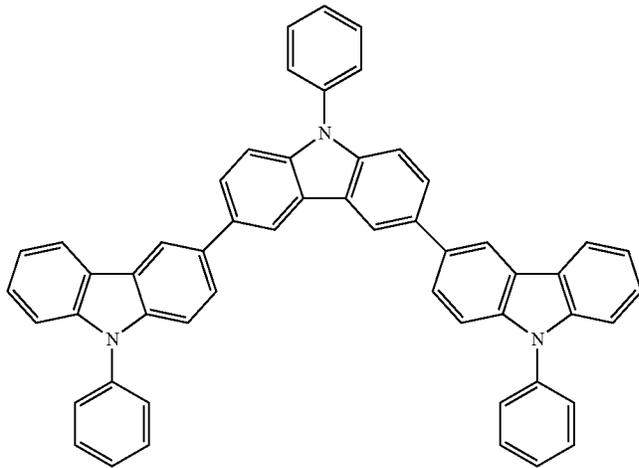
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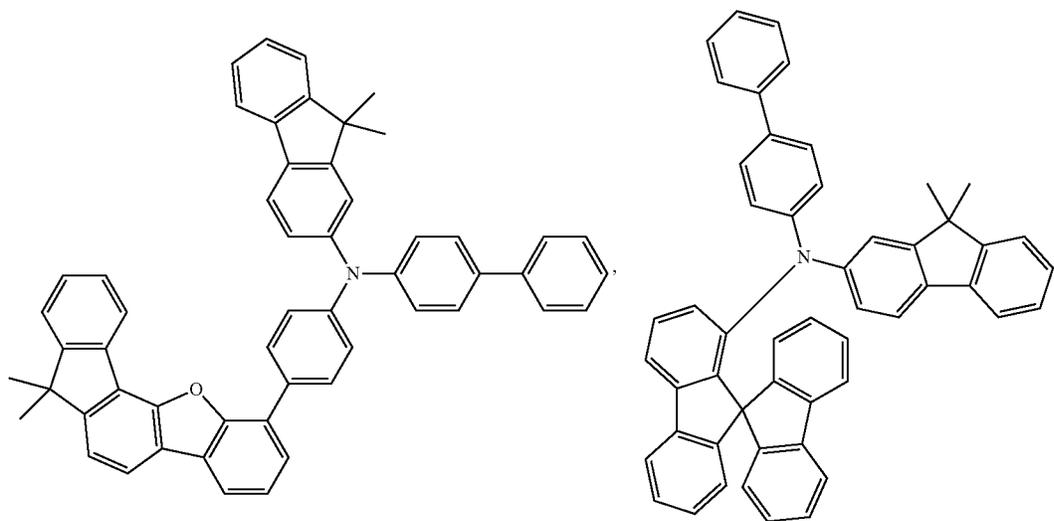
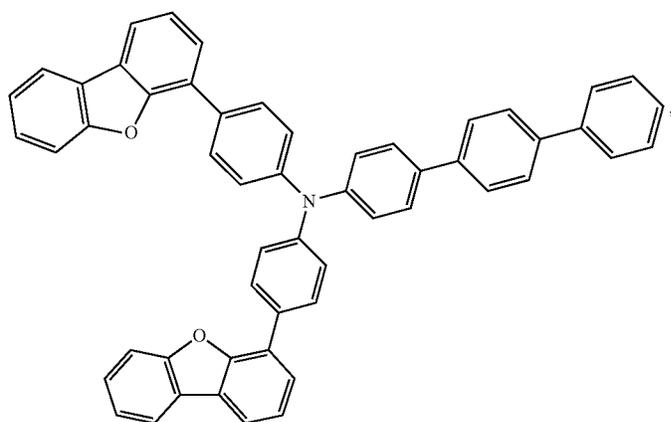
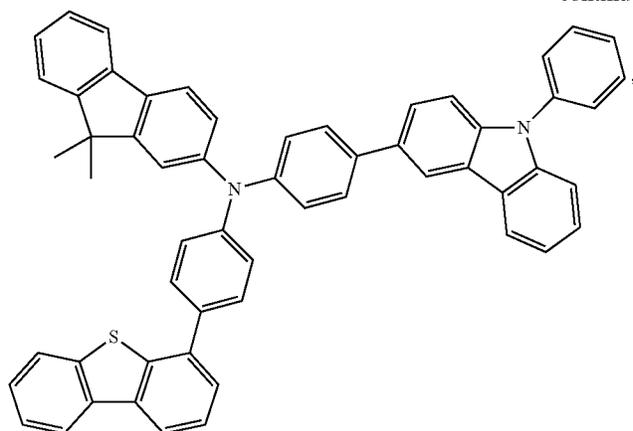
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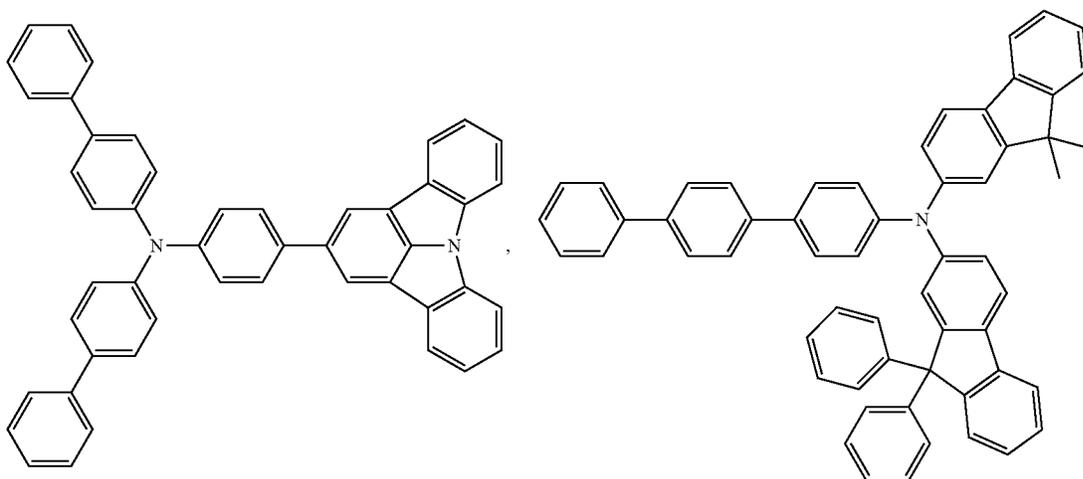
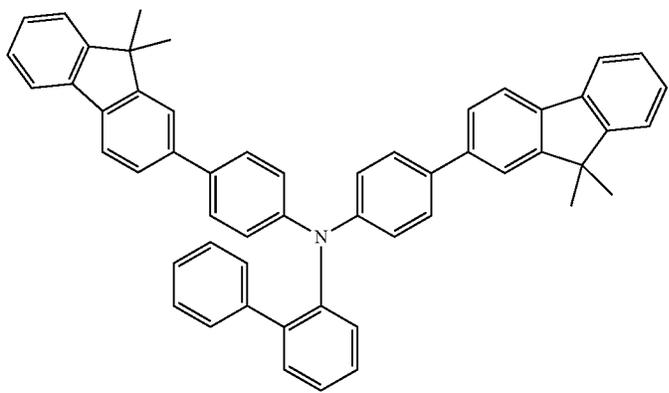
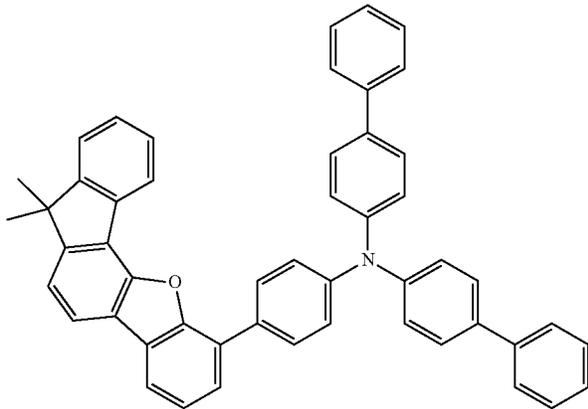
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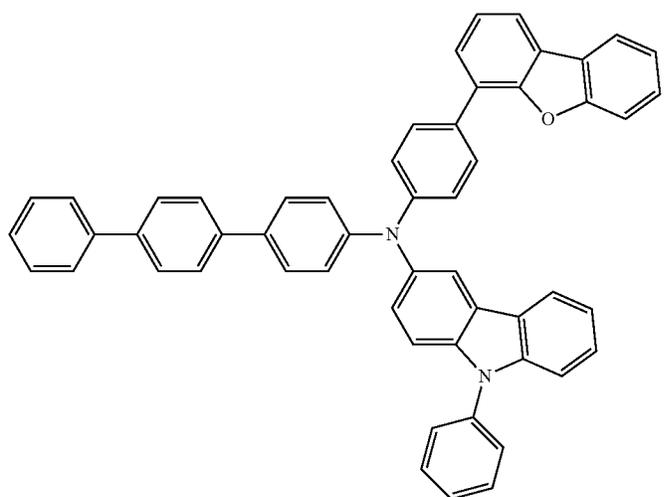
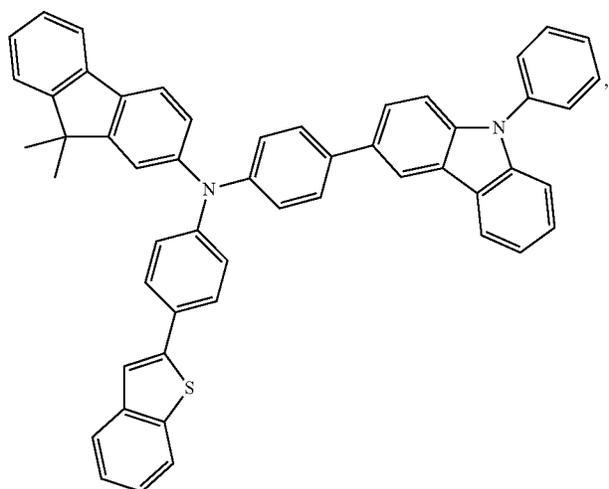
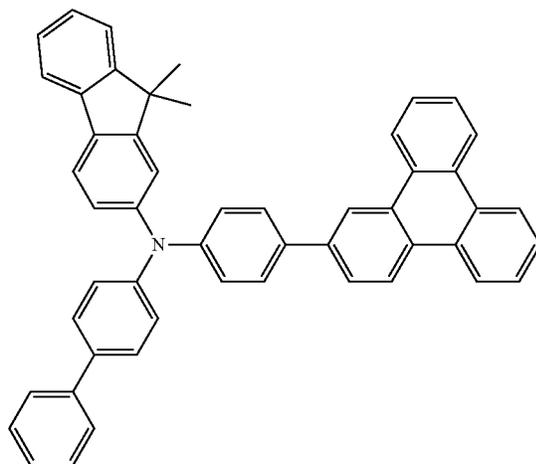
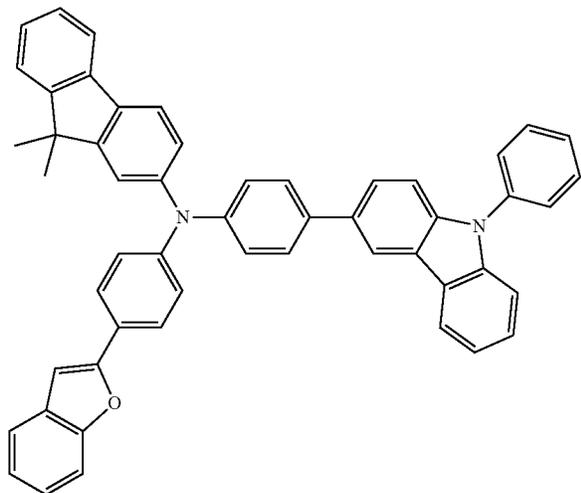
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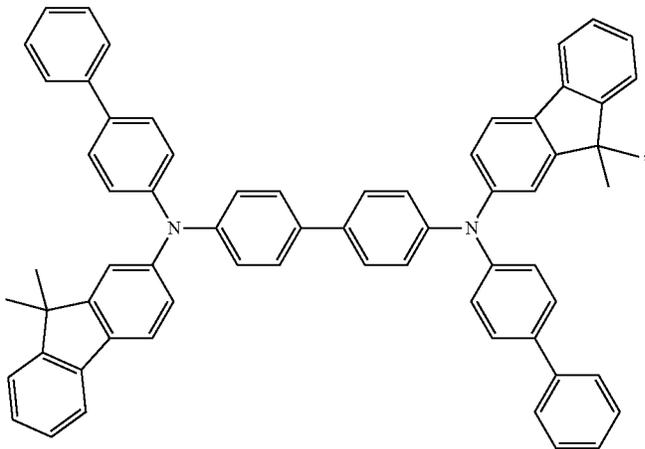
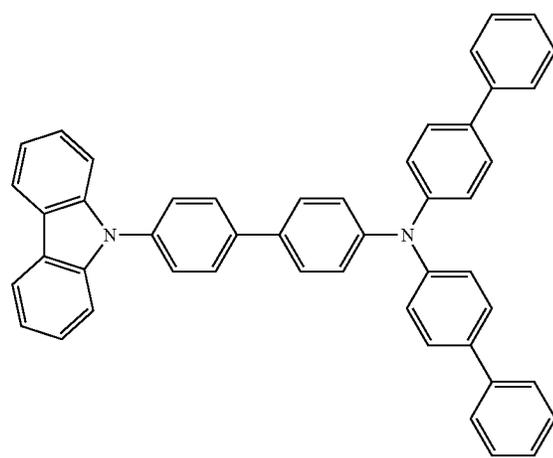
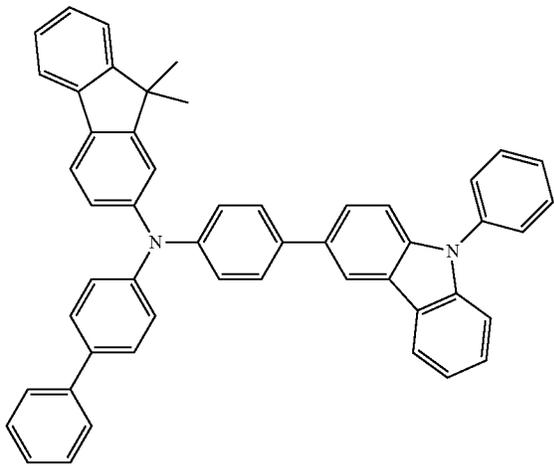
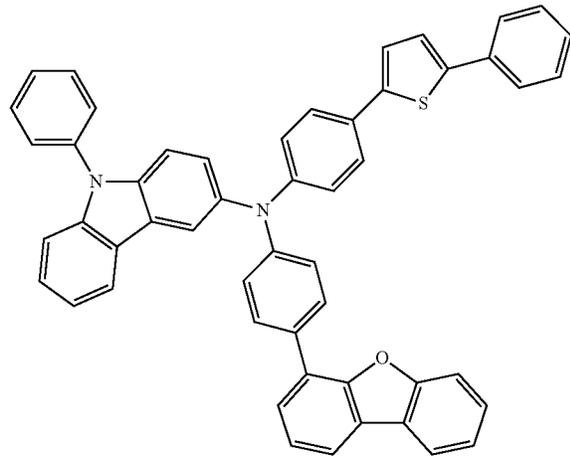
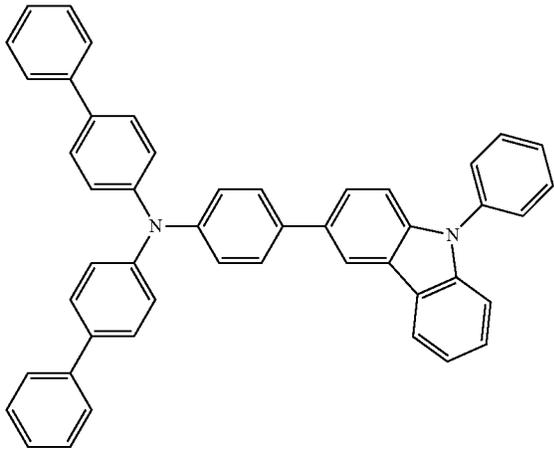
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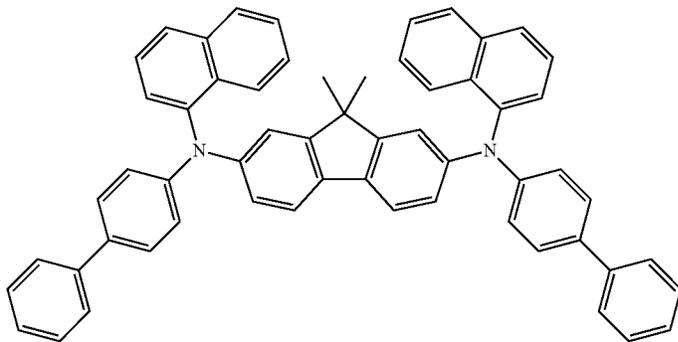
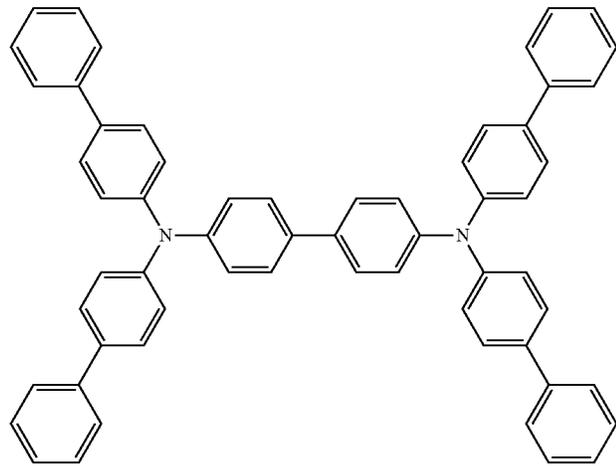
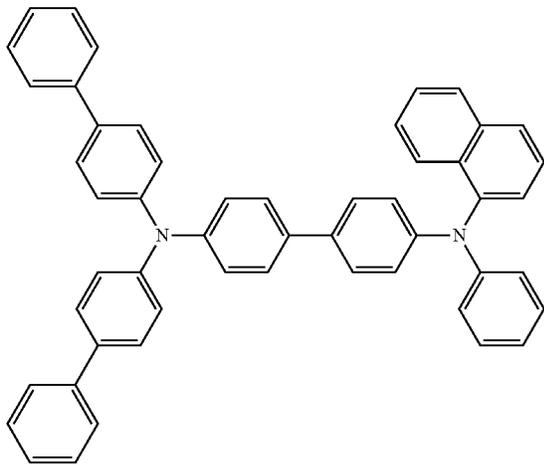
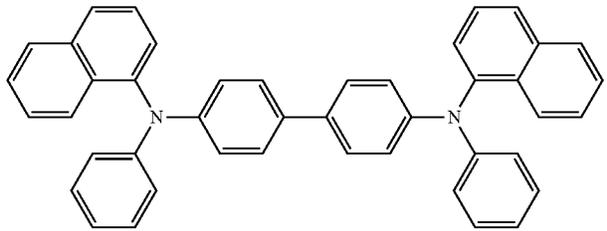
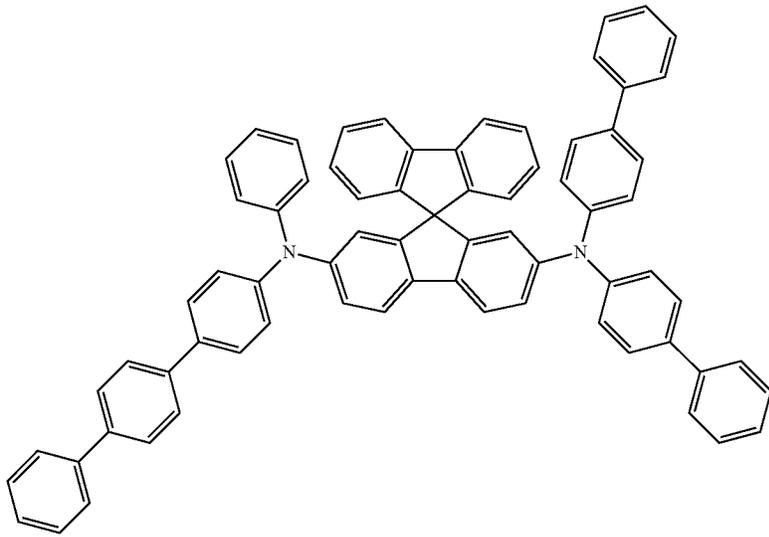
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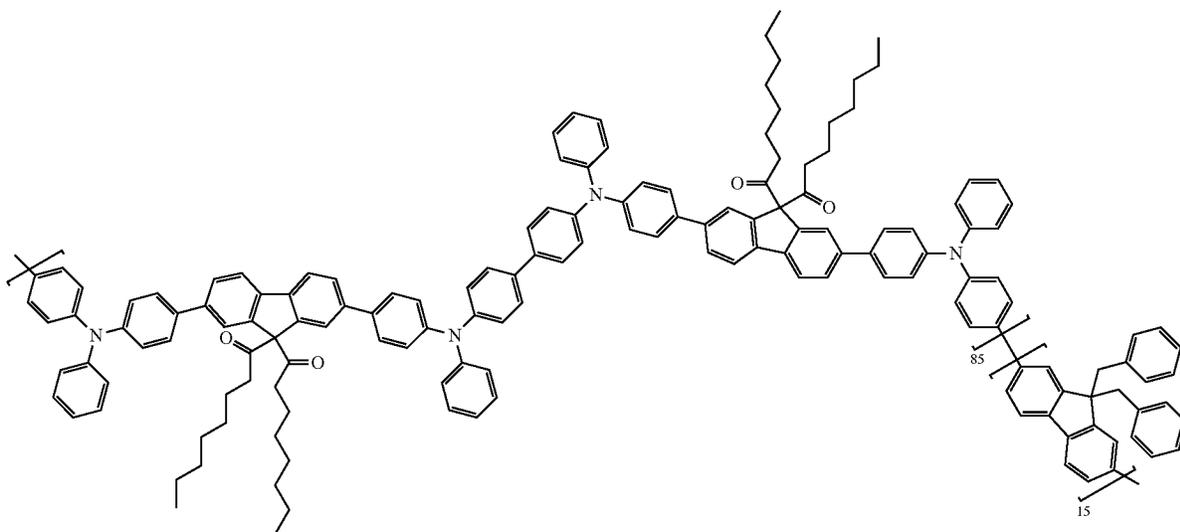
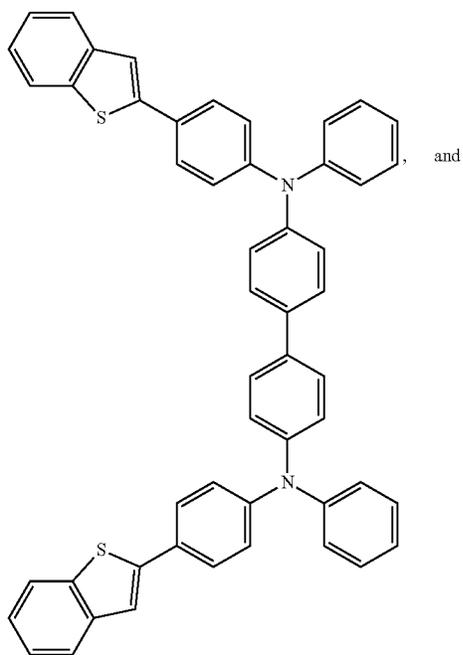
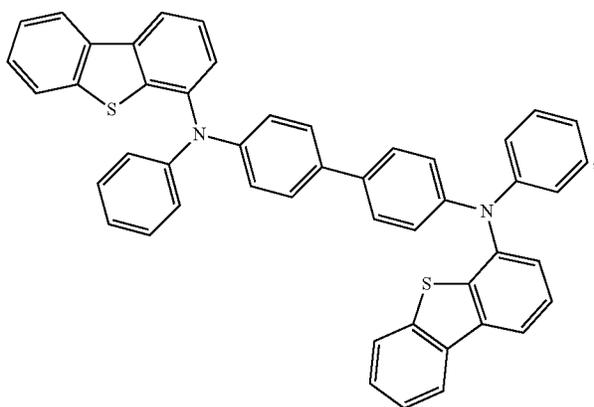
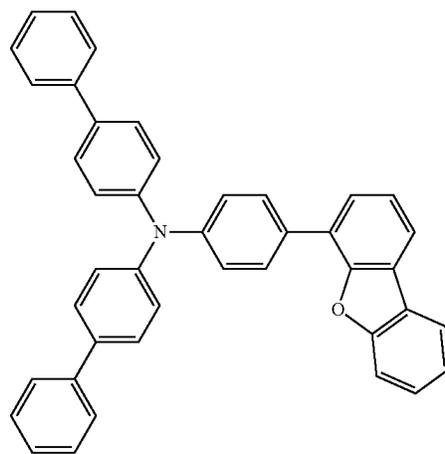
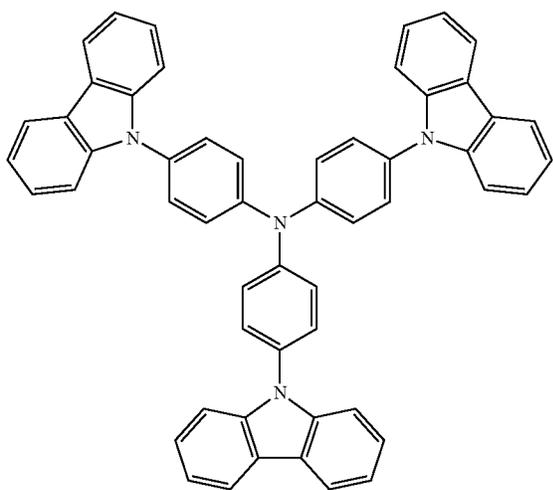
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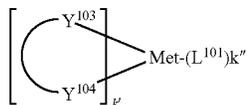
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EBL:

An electron blocking layer (EBL) may be used to reduce the number of electrons and/or, excitons that leave the emissive layer. The presence of such a blocking layer in a device may result in substantially higher efficiencies, and or, longer lifetime, as compared to a similar device lacking a blocking layer. Also, a blocking layer may be used to confine emission to a desired region of an OLED. In some embodiments, the EBL material has a higher LUMO (closer to the vacuum level) and/or higher triplet energy than the emitter closest to the EBL interface. In some embodiments, the EBL material has a higher LUMO (closer to the vacuum level) and or higher triplet energy than one or more of the hosts closest to the EBL interface. In one aspect, the compound used in EBL contains the same molecule or the same functional groups used as one of the hosts described below. Additional Hosts:

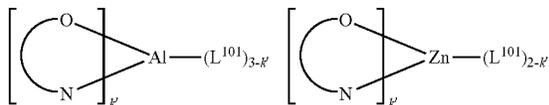
The light emitting layer of the organic EL device of the present invention preferably contains at least a metal complex as light emitting dopant material, and may contain one or more additional host materials using the metal complex as a dopant material. Examples of the host material are not particularly limited, and any metal complexes or organic compounds may be used as long as the triplet energy of the host is larger than that of the dopant. Any host material may be used with any dopant so long as the triplet criteria is satisfied.

Examples of metal complexes used as host are preferred have the following general formula:



wherein Met is a metal; (Y<sup>103</sup>-Y<sup>104</sup>) is a bidentate ligand, Y<sup>103</sup> and Y<sup>104</sup> are independently selected from C, N, O, P, and S; L<sup>101</sup> is an another ligand; k' is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and k'+k'' is the maximum number of ligands that may be attached to the metal.

In one aspect, the metal complexes are:



wherein (O—N) is a bidentate ligand, having metal coordinated to atoms O and N.

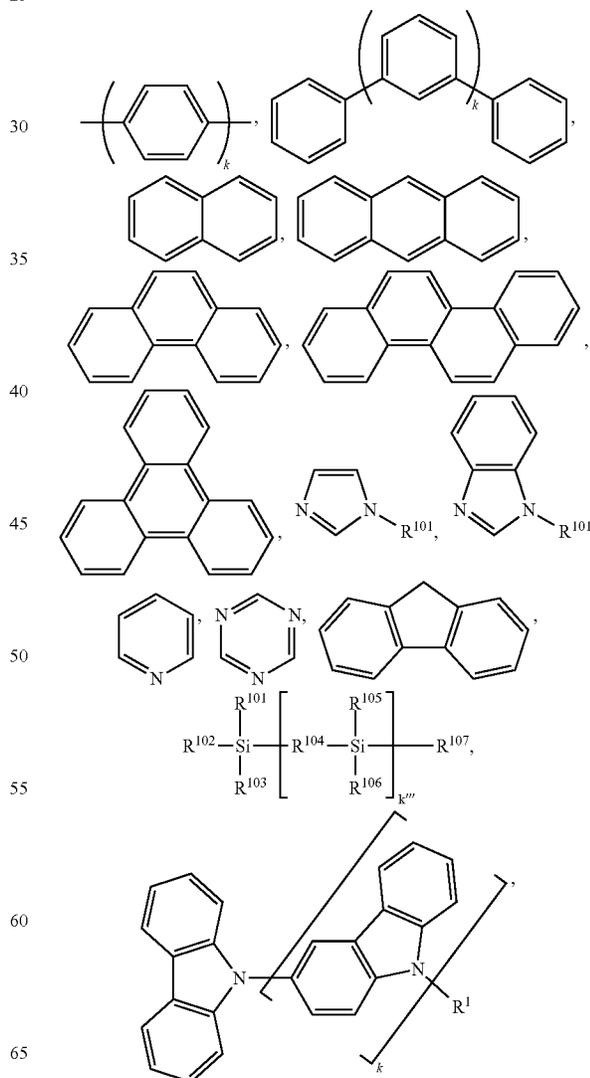
In another aspect, Met is selected from Ir and Pt. In a further aspect, (Y<sup>103</sup>-Y<sup>104</sup>) is a carbene ligand.

Examples of other organic compounds used as additional host are selected from the group consisting of aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine,

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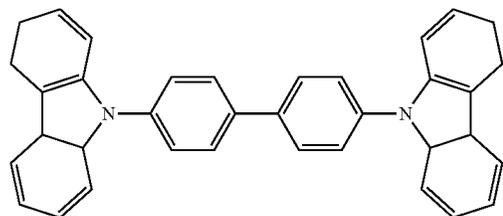
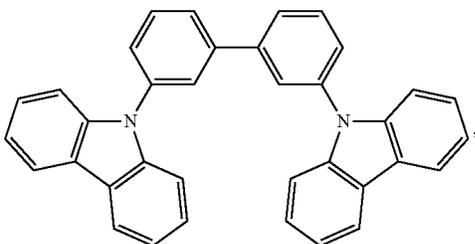
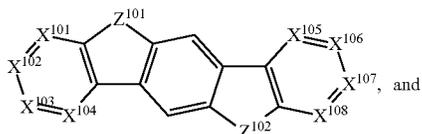
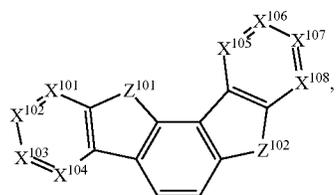
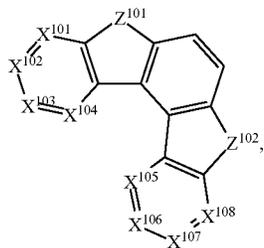
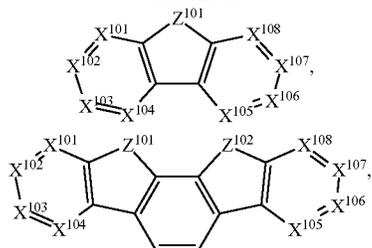
oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuroypyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atom, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each group is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, host compound contains at least one of the following groups in the molecule:



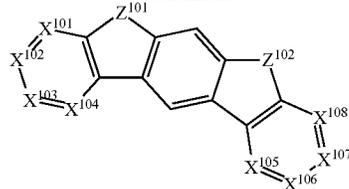
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wherein R<sup>101</sup> to R<sup>107</sup> is independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, alkoxy, aryloxy, amino, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above. k is an integer from 0 to 20 or 1 to 20; k'' is an integer from 0 to 20. X<sup>101</sup> to X<sup>108</sup> is selected from C (including CH) or N.

Z<sup>101</sup> and Z<sup>102</sup> is selected from NR<sup>101</sup>, O, or S.

Non-limiting examples of the additional host materials that may be used in an MED in combination with the host compound disclosed herein are exemplified below together with references that disclose those materials: EP2034538, EP2757608, JP2007254297, EP2034538A, EP2757608, JP2007254297, KR20100079458, KR20120088644, KR20120129733, KR20130115564, TW201329200, US20030175553, US20050238919, US20060280965, US20090017330, US20090030202, US20090167162, US20090302743, US20090309488, US20100012931, US20100084966, US20100187984, US2010187984, US2012075273, US2012126221, US2013009543, US2013105787, US2013175519, US2014001446, US20140183503, US20140225088, US2014034914, U.S. Pat. No. 7,154,114, WO2001039234, WO2004093207, WO2005014551, WO2005089025, WO2006072002, WO2006114966, WO2007063754, WO2008056746, WO2009003898, WO2009021126, WO2009063833, WO2009066778, WO2009066779, WO2009086028, WO2010056066, WO2010107244, WO2011081423, WO2011081431, WO2011086863, WO2012128298, WO2012133644, WO2012133649, WO2013024872, WO2013035275, WO2013081315, WO2013191404, WO2014142472,

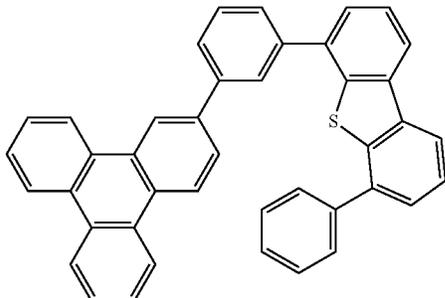
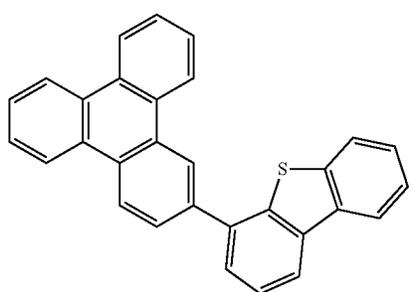
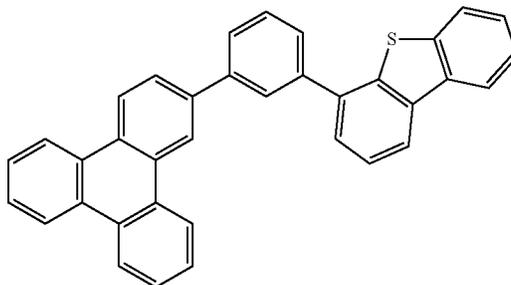
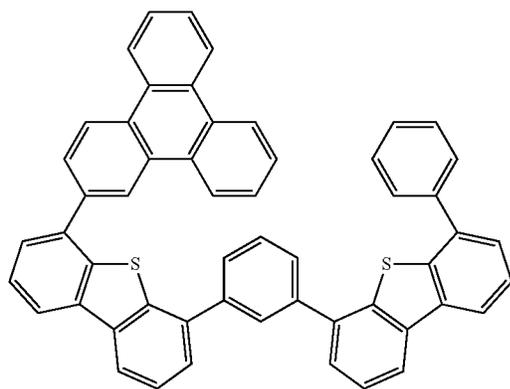
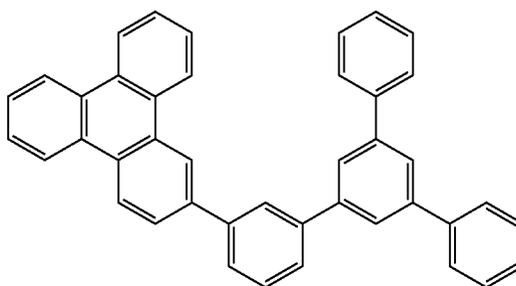
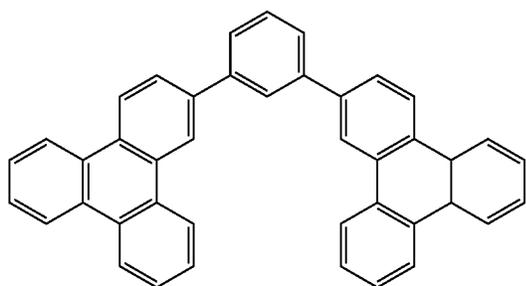
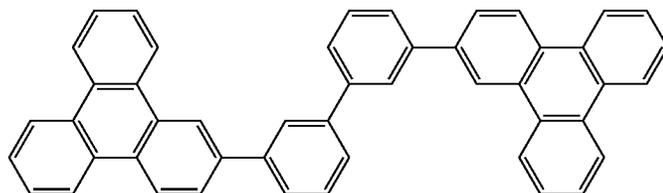
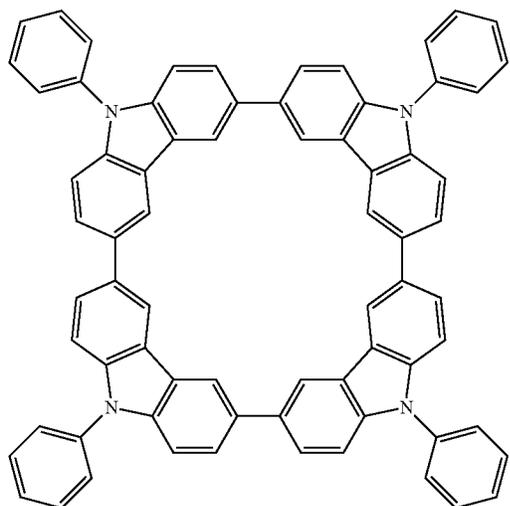
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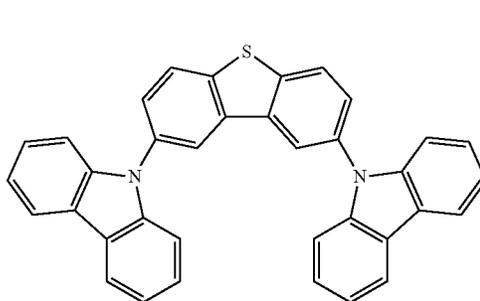
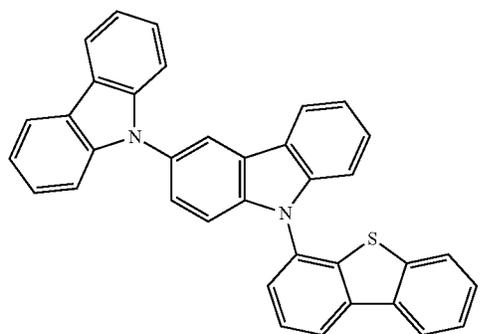
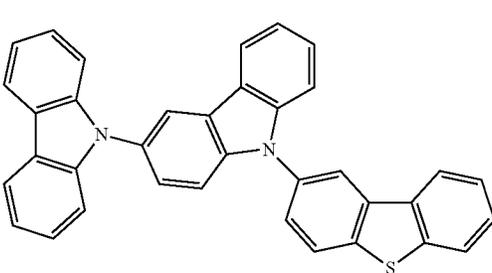
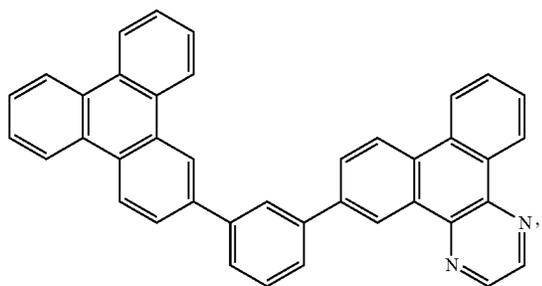
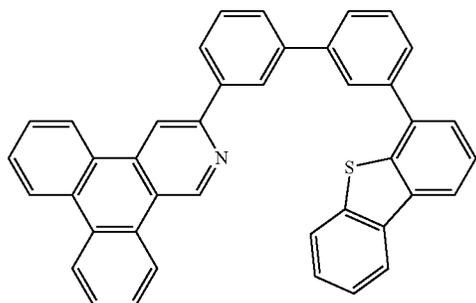
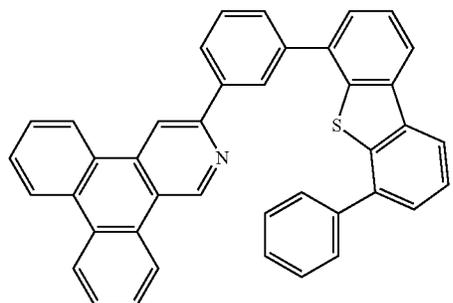
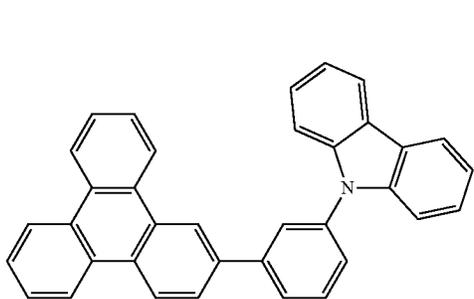
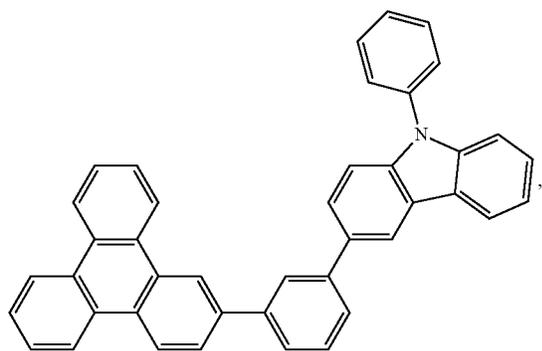
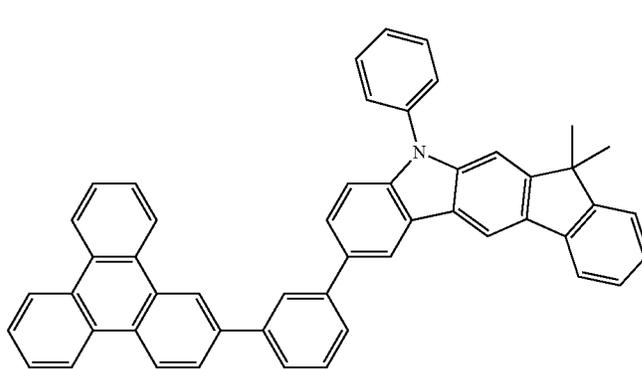
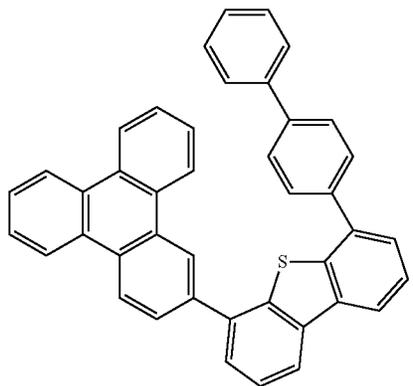
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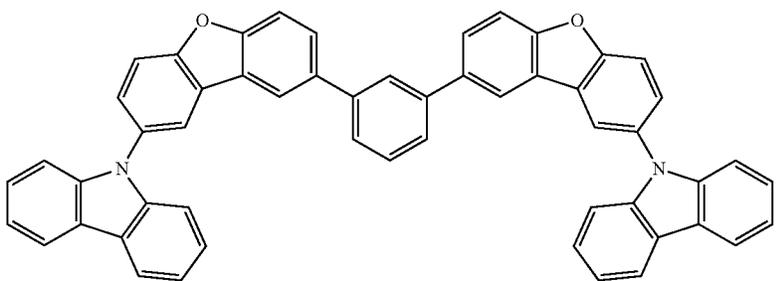
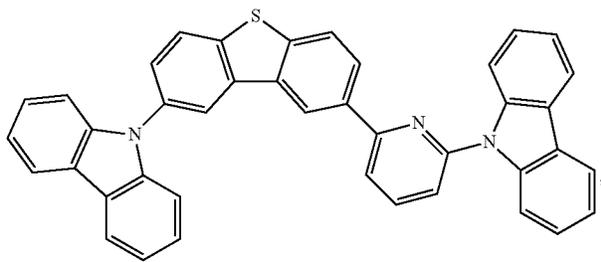
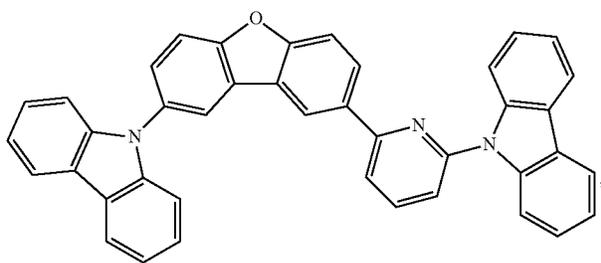
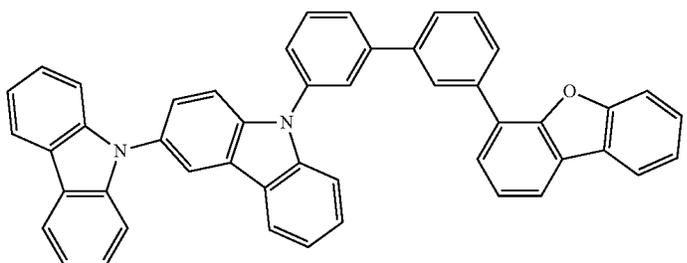
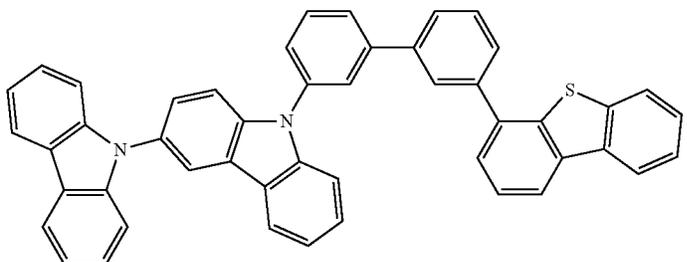
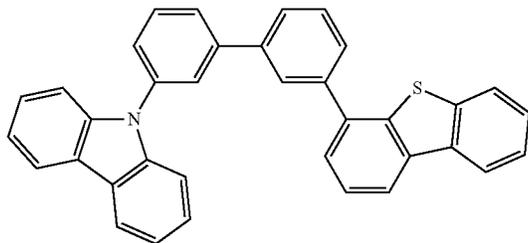
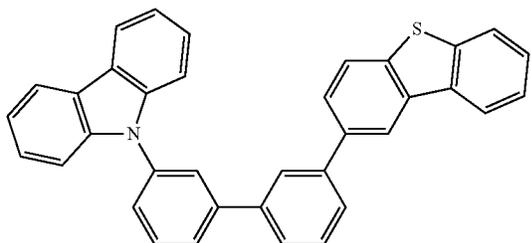
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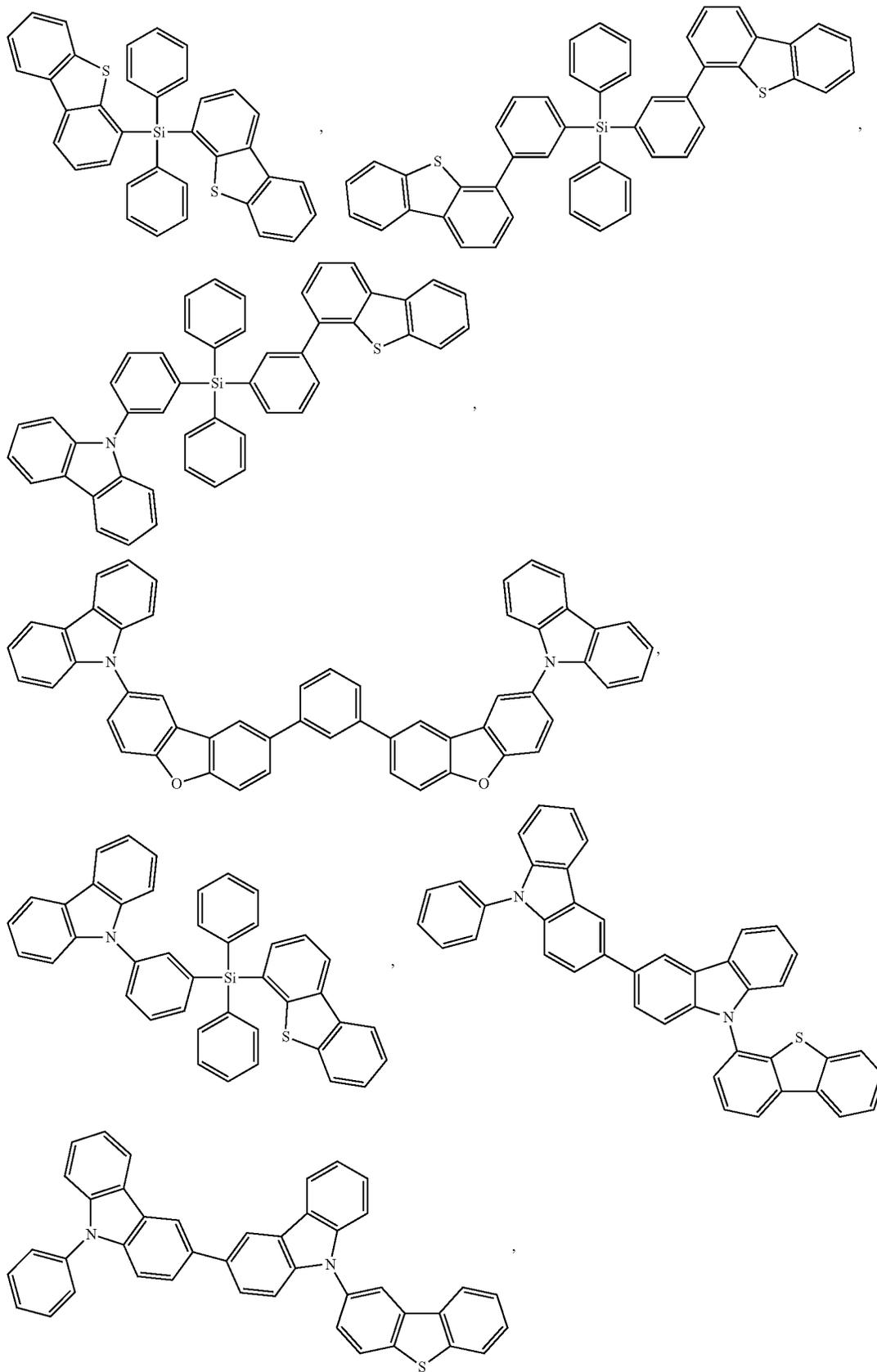
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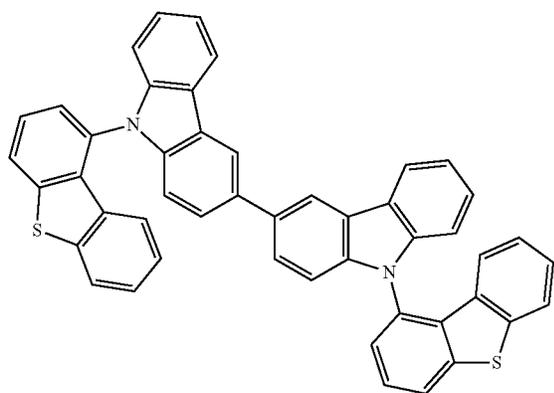
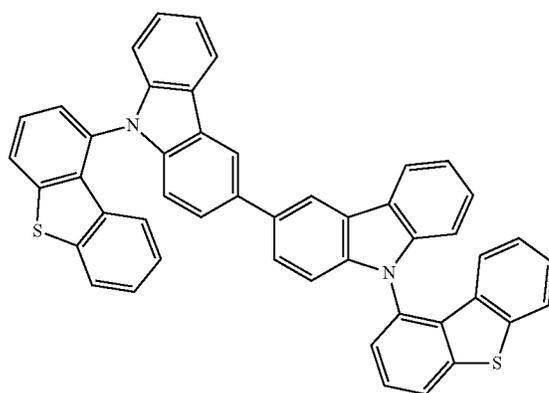
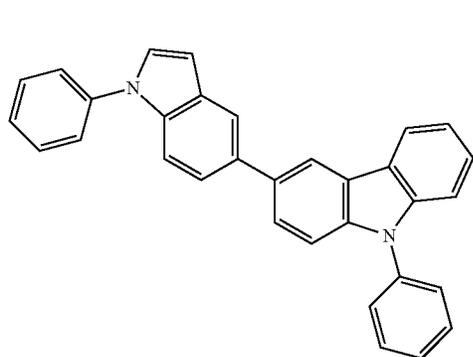
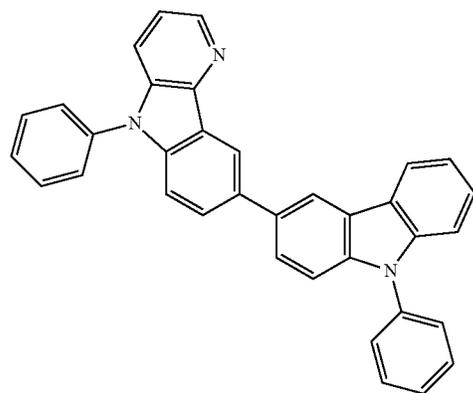
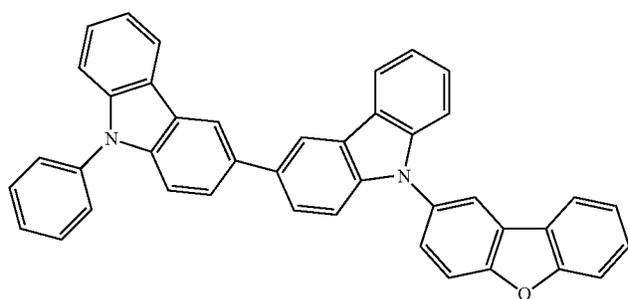
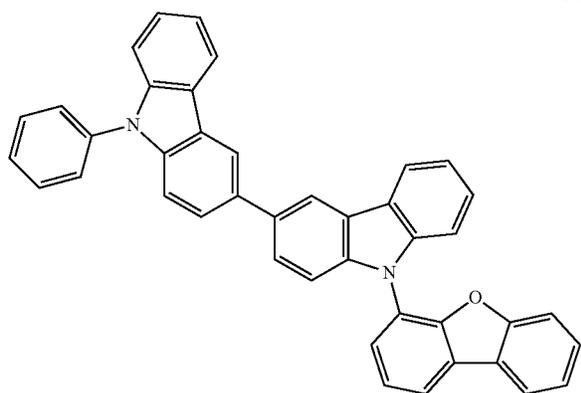
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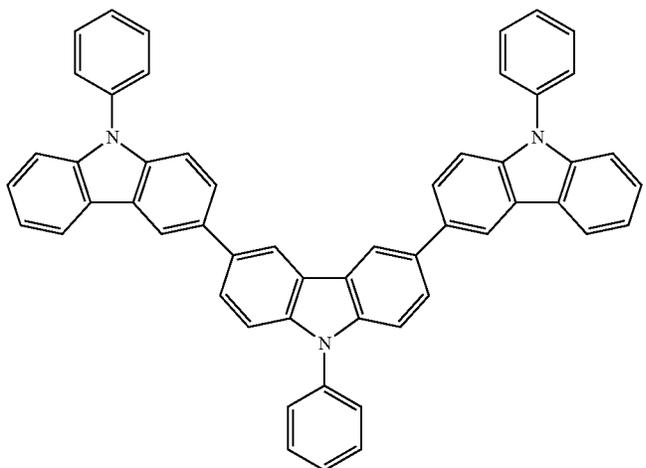
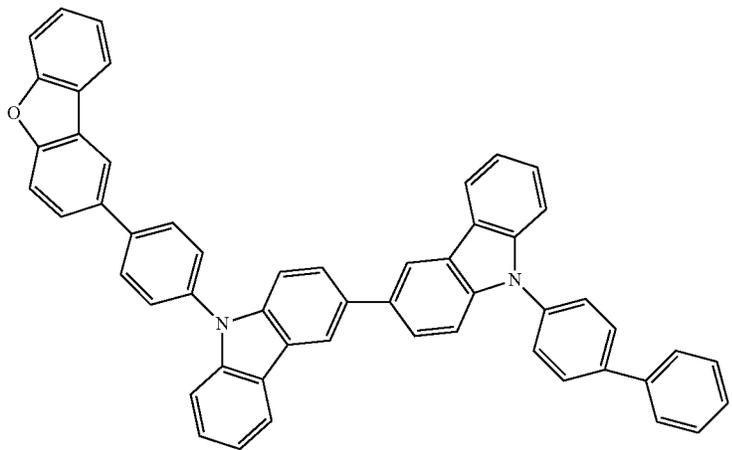
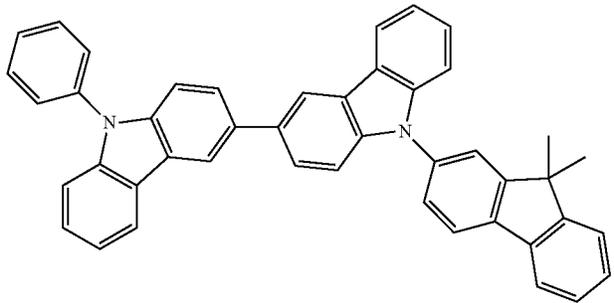
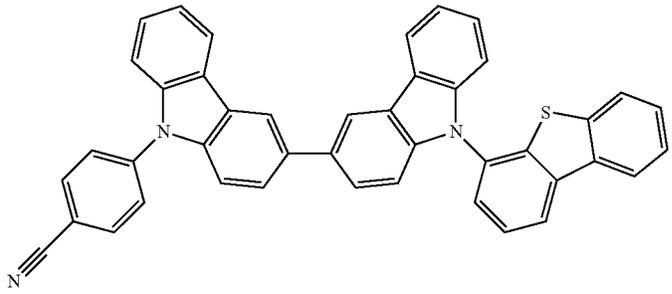
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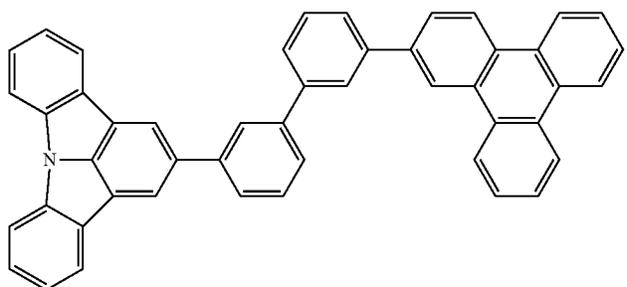
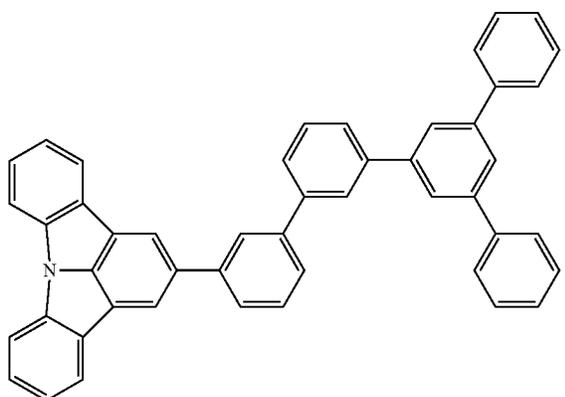
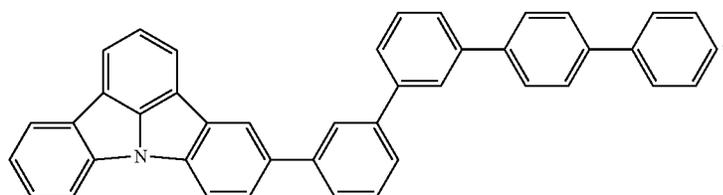
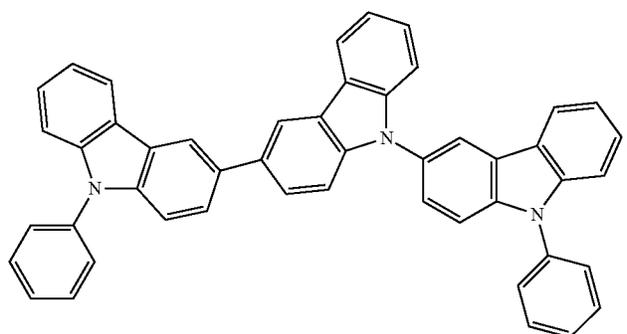
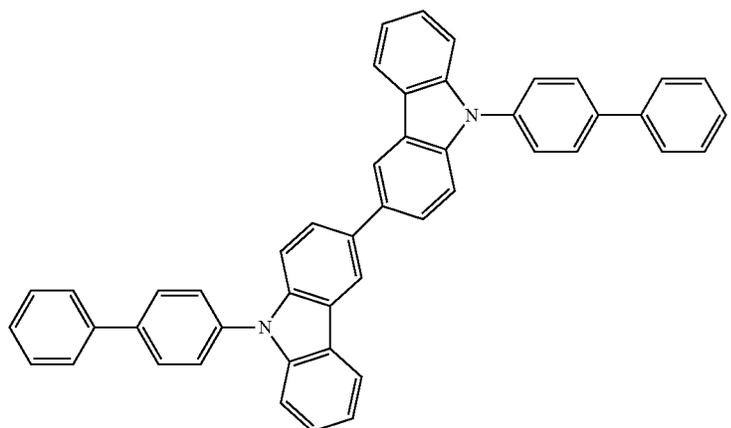
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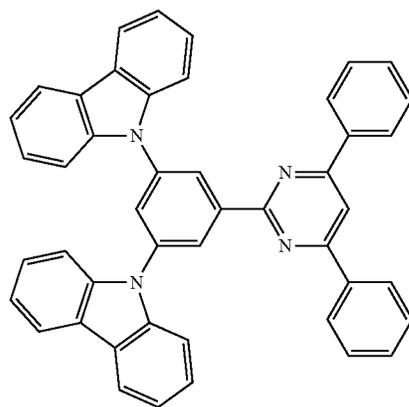
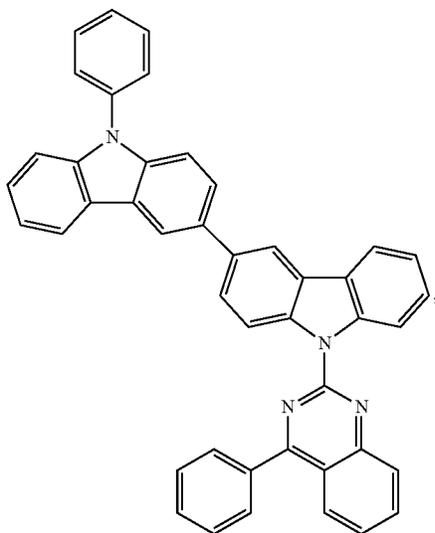
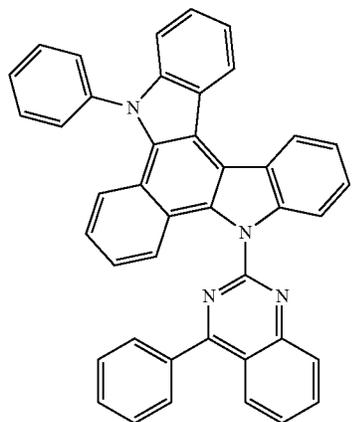
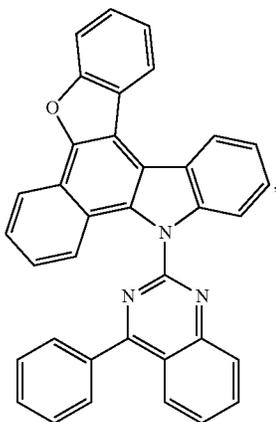
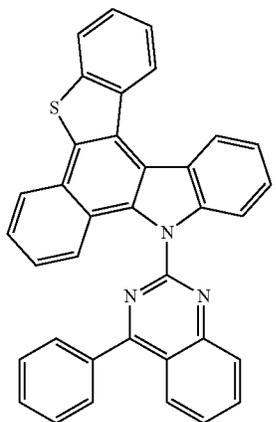
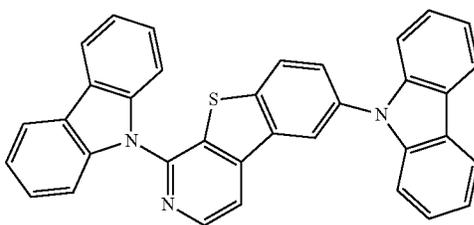
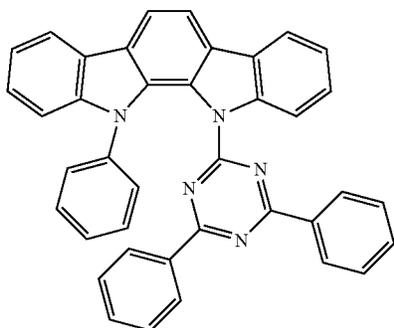
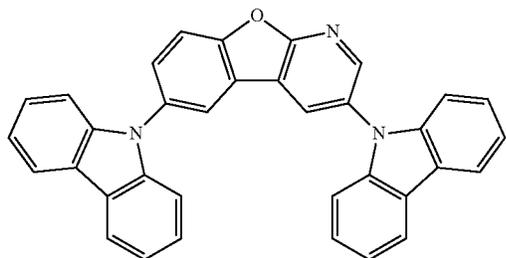
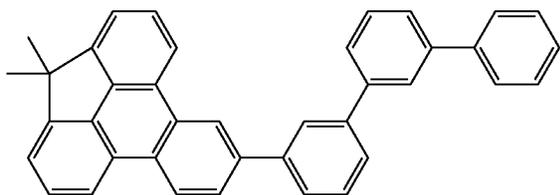
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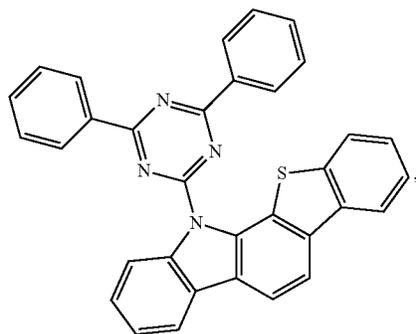
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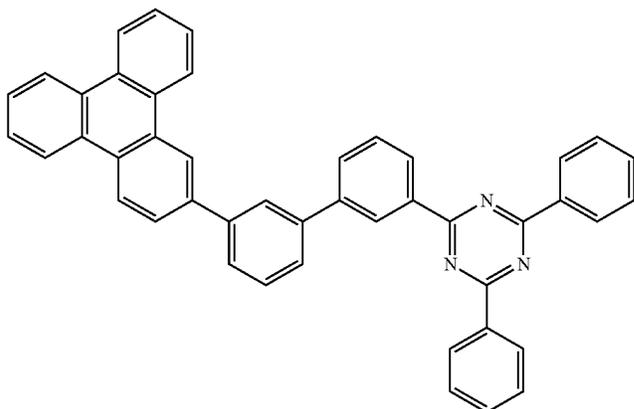
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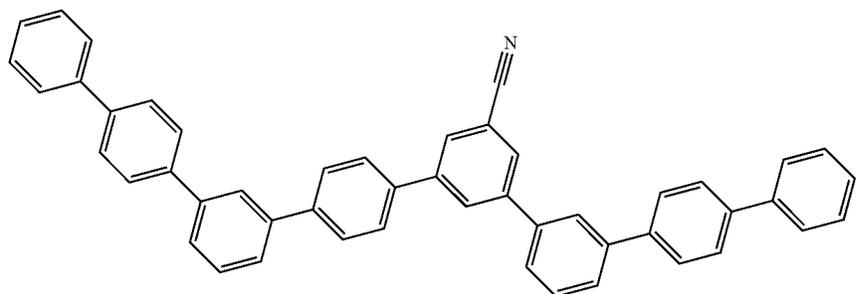
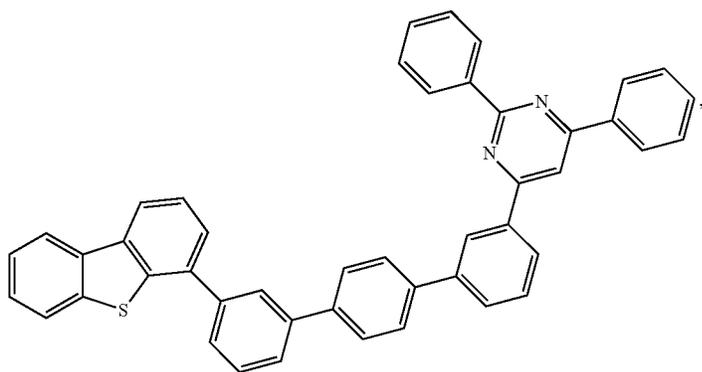
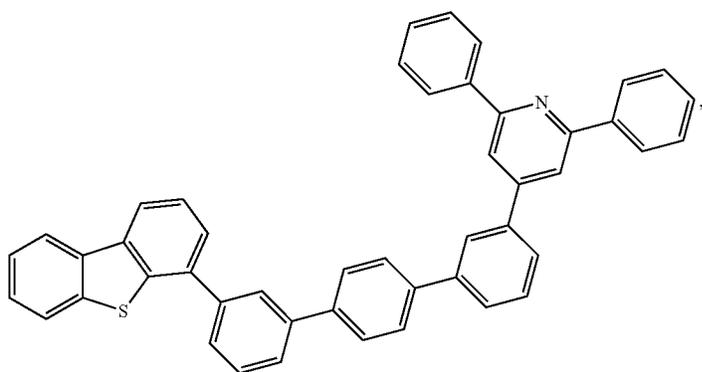
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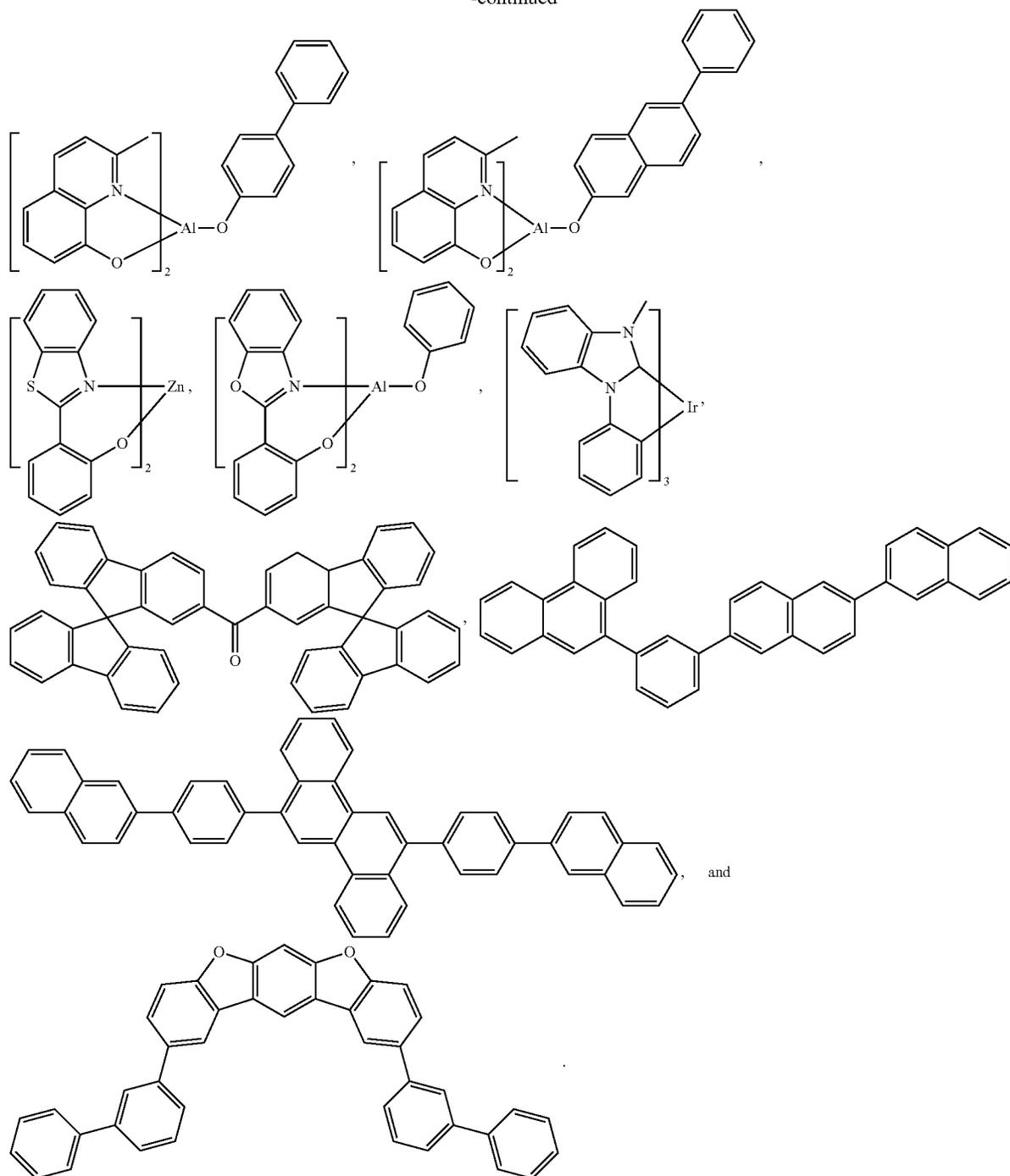
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## Emitter:

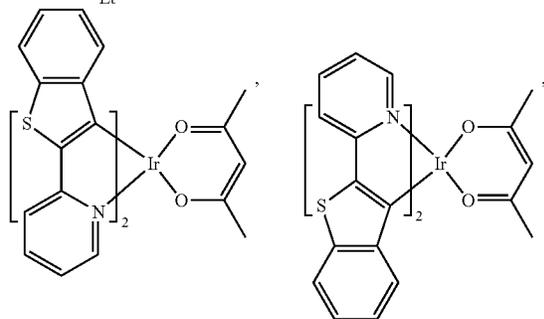
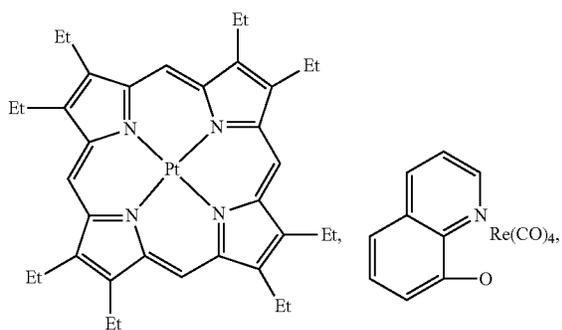
An emitter example is not particularly limited, and any compound may be used as long as the compound is typically used as an emitter material. Examples of suitable emitter materials include, but are not limited to, compounds which can produce emissions via phosphorescence, fluorescence, thermally activated delayed fluorescence, i.e., TADF (also referred to as E-type delayed fluorescence), triplet-triplet annihilation, or combinations of these processes.

Non-limiting examples of the emitter materials that may be used in an MED in combination with materials disclosed

herein are exemplified below together with references that disclose those materials: CN103694277, CN1696137, 0301238981, EP01239526, EP01961743, EP1239526, EP1244155, EP1642951, EP1647554, EP1841834, EP1841834B, EP2062907, EP2730583, JP2012074444, JP2013110263, JP4478555, KR1020090133652, KR20120032054, KR20130043460, TW201332980, US06699599, US06916554, US20010019782, US20020034656, US20030068526, US20030072964, US20030138657, US20050123788, US20050244673, US2005123791, US2005260449, US20060008670,

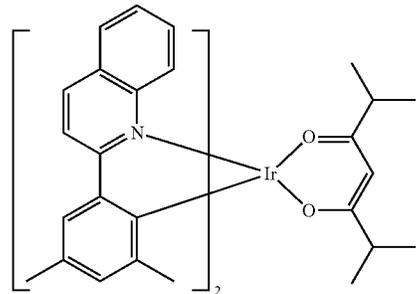
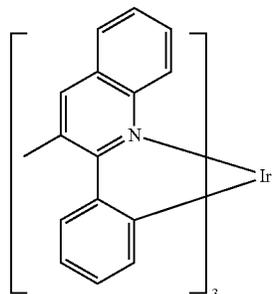
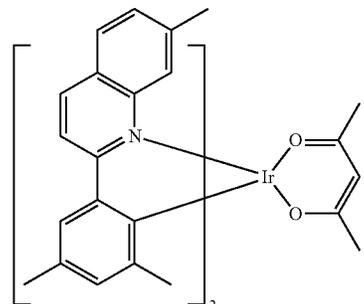
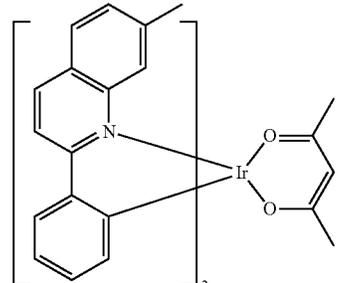
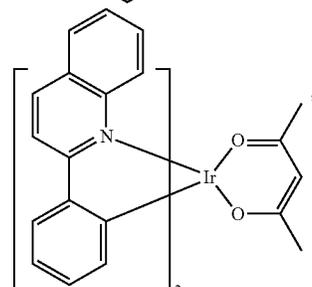
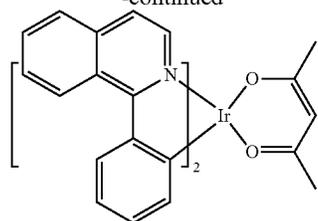
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 WO2010054731, WO2010086089, WO2010118029, 35  
 WO2011044988, WO2011051404, WO2011107491,  
 WO2012020327, WO2012163471, WO2013094620,  
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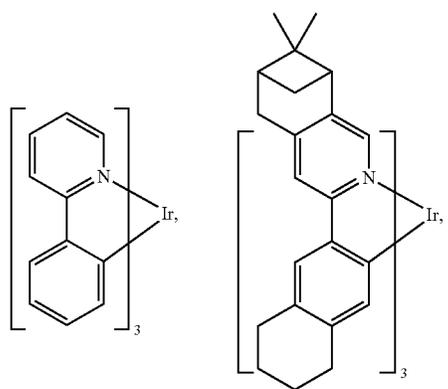
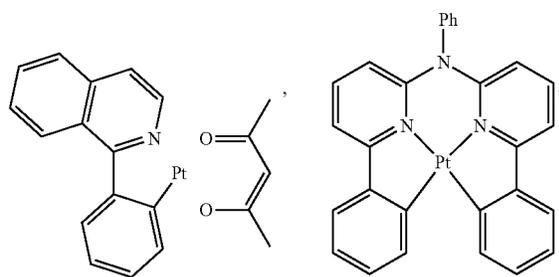
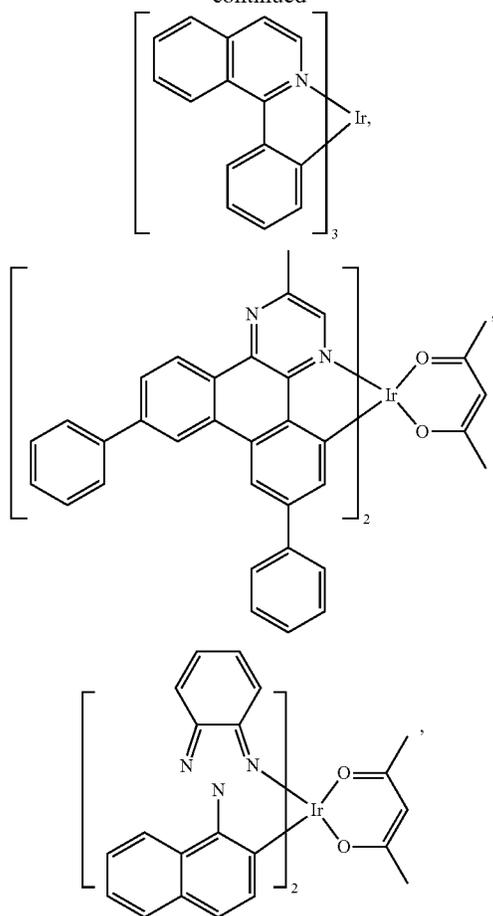
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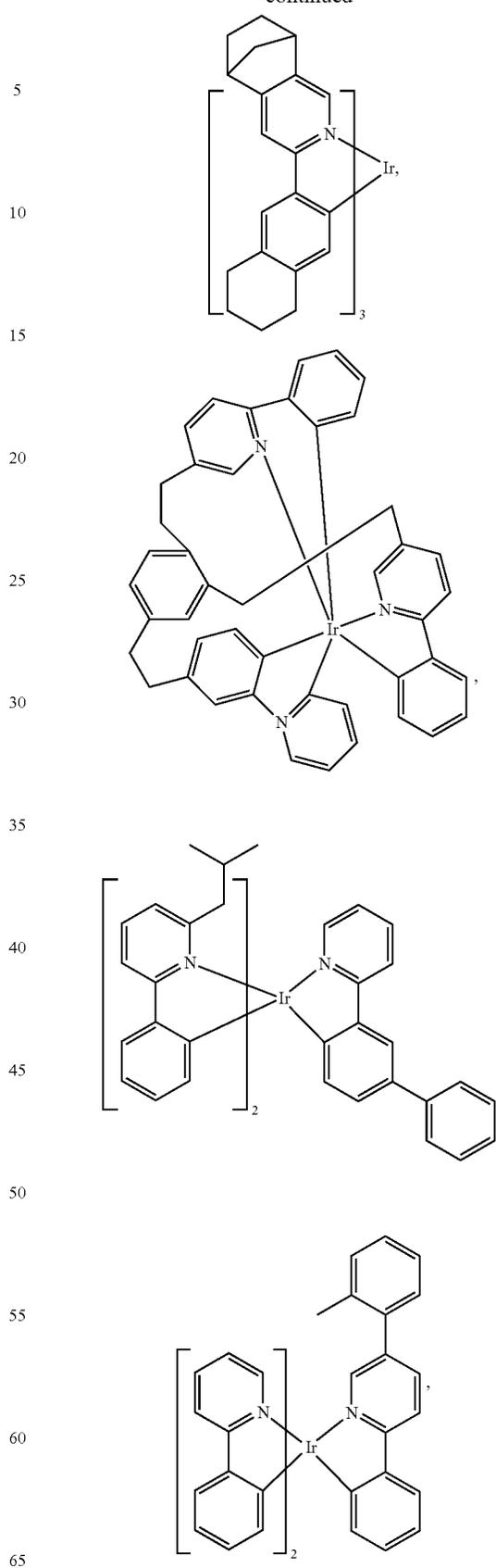
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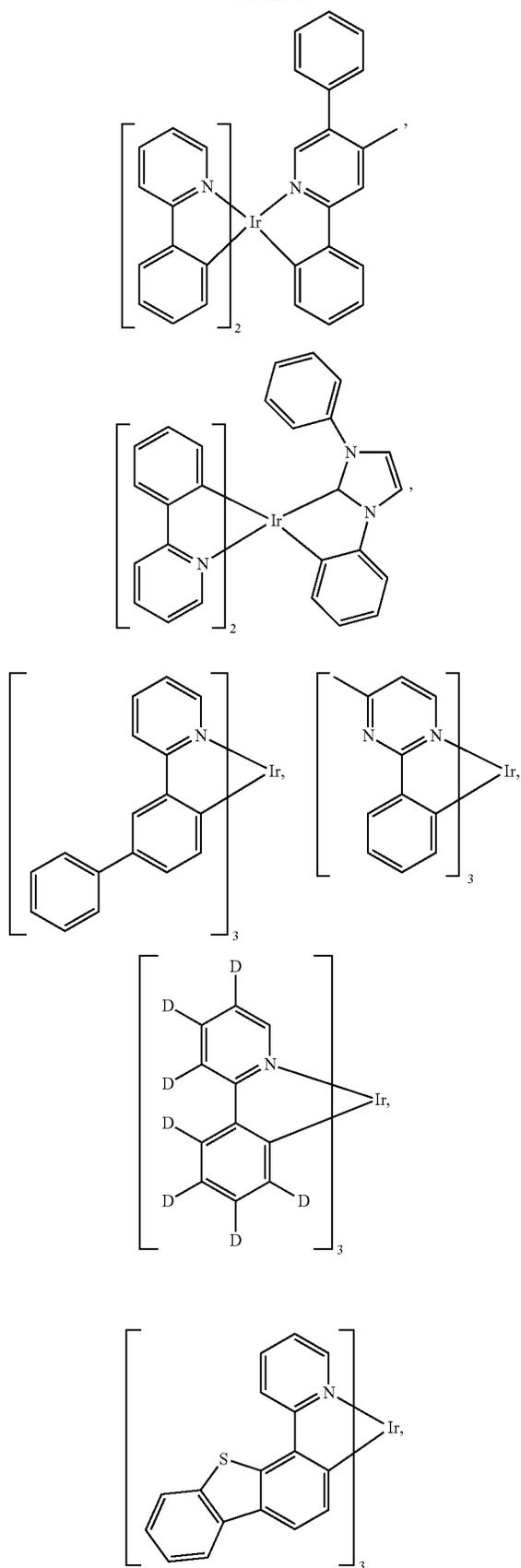
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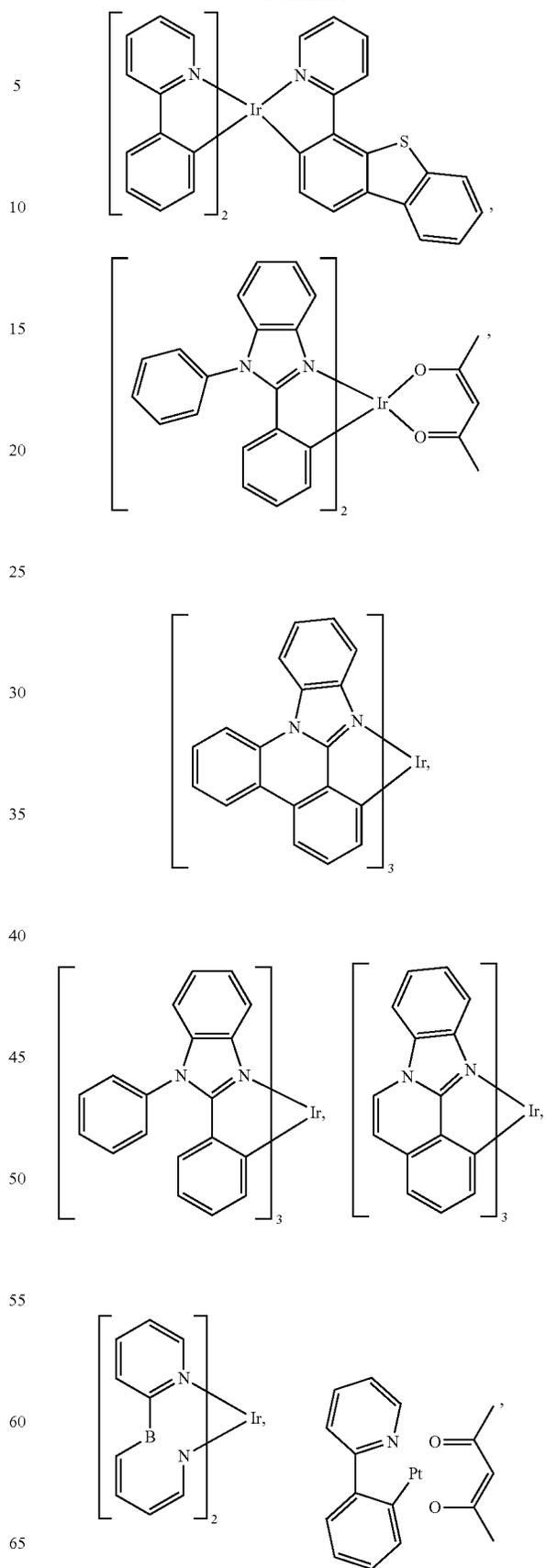
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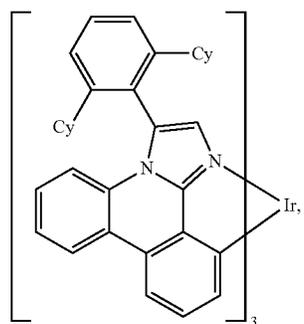
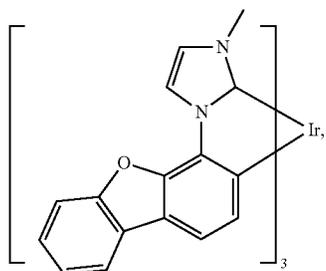
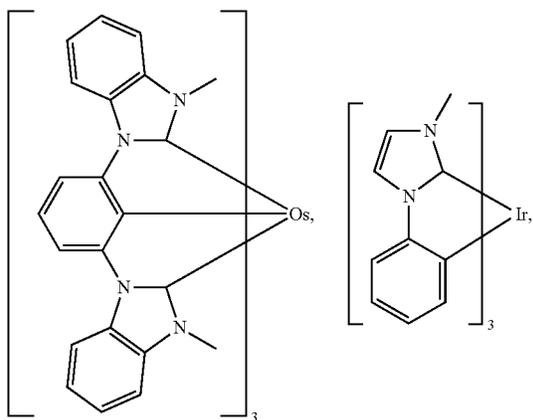
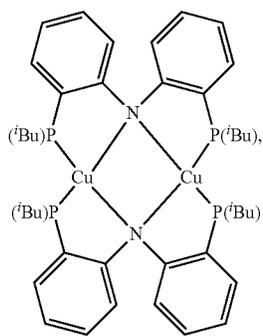
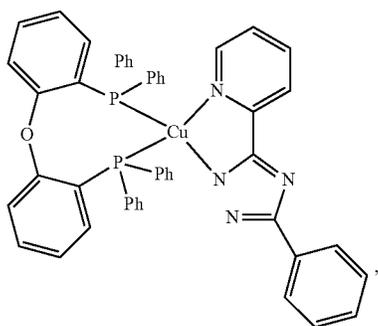
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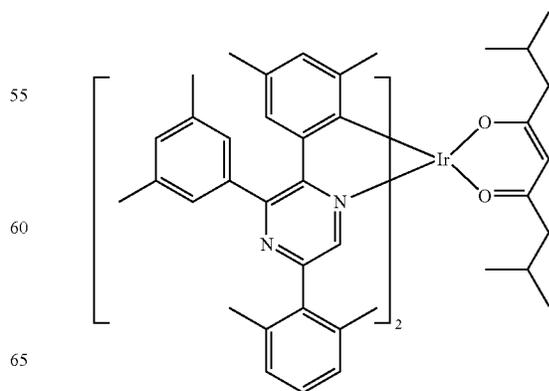
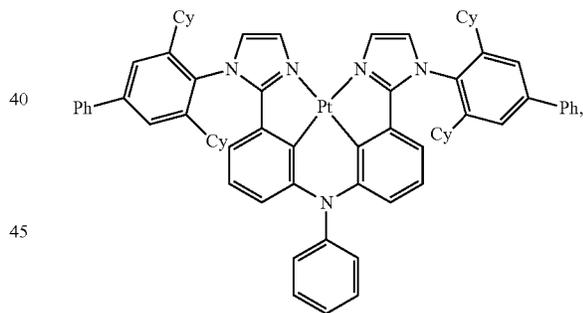
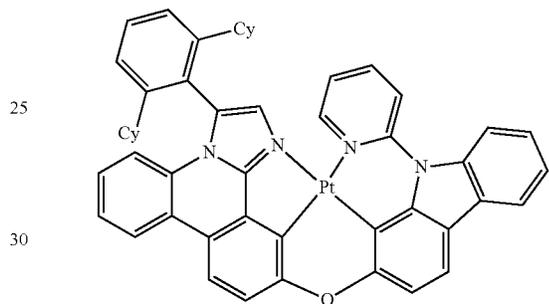
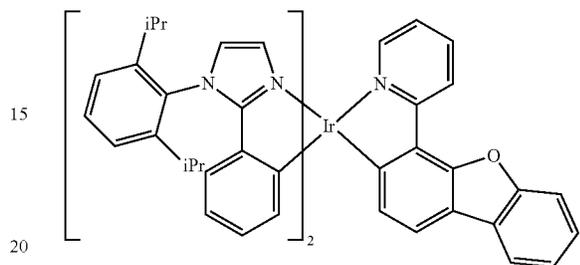
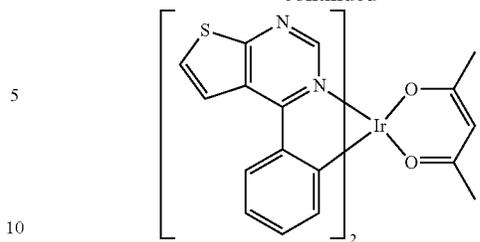
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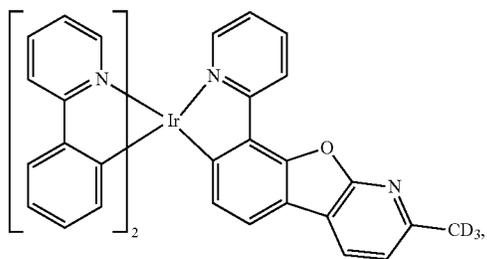
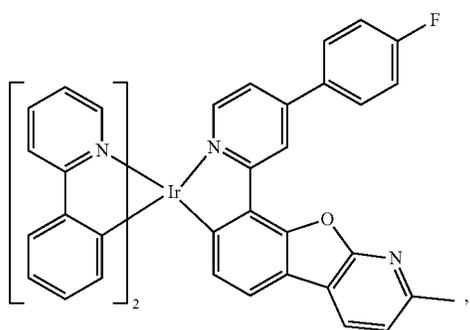
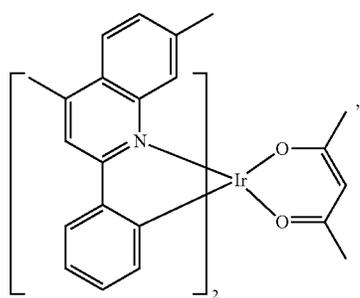
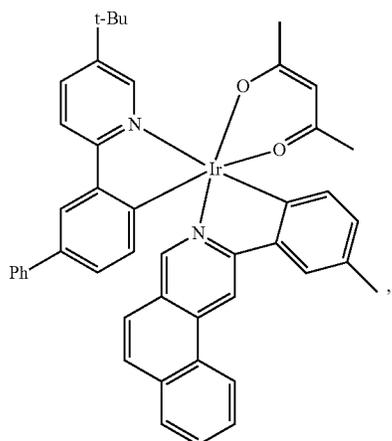
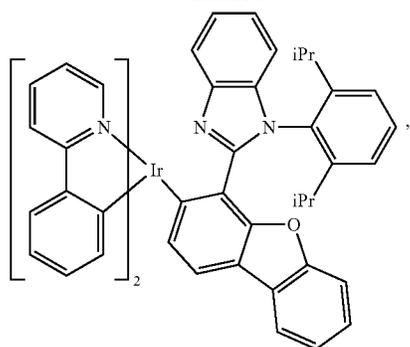
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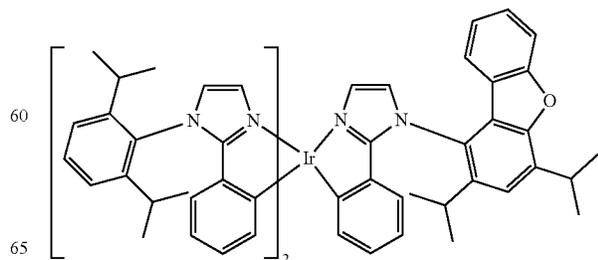
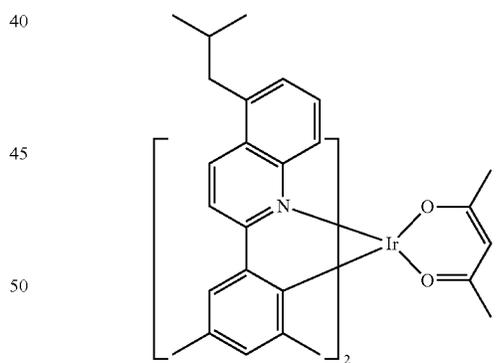
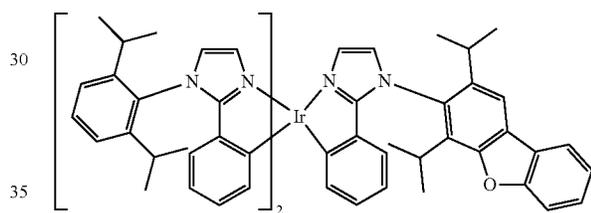
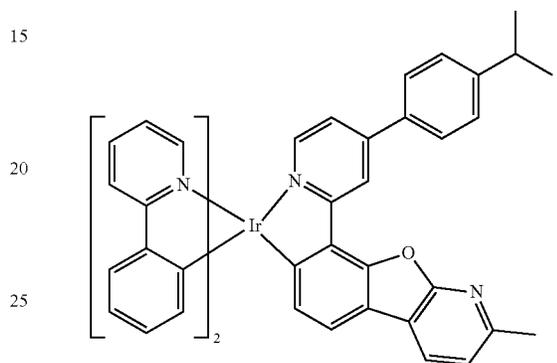
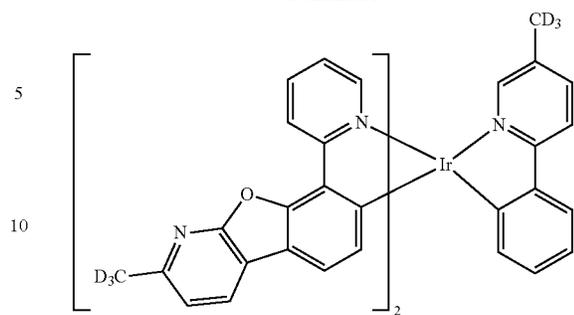
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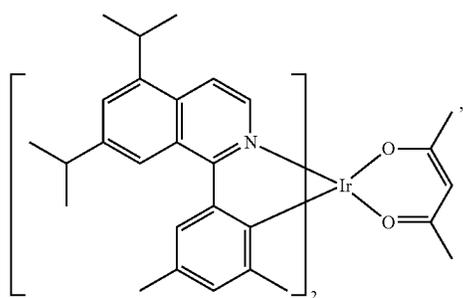
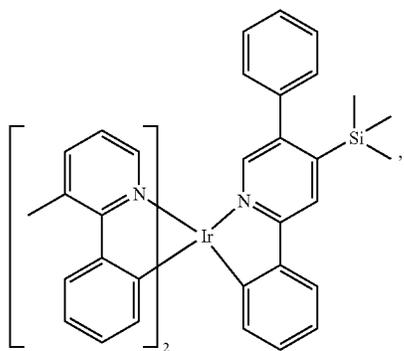
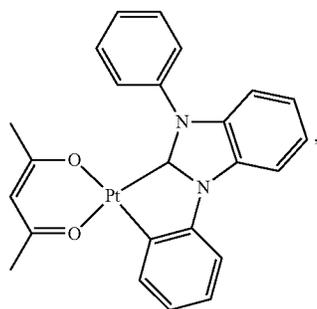
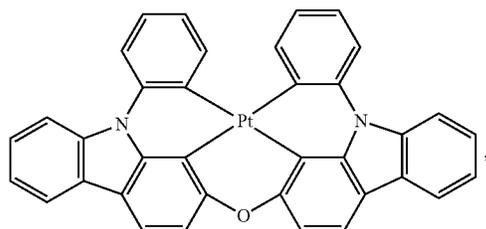
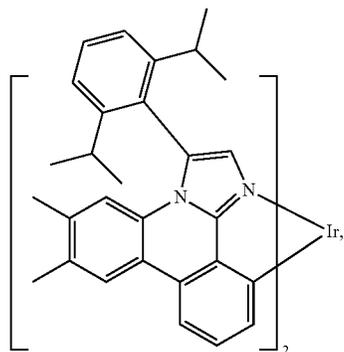
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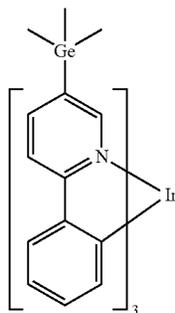
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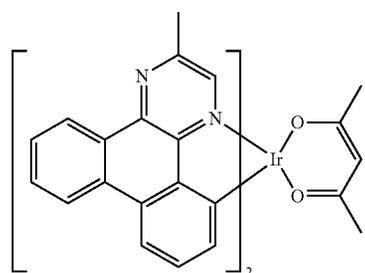
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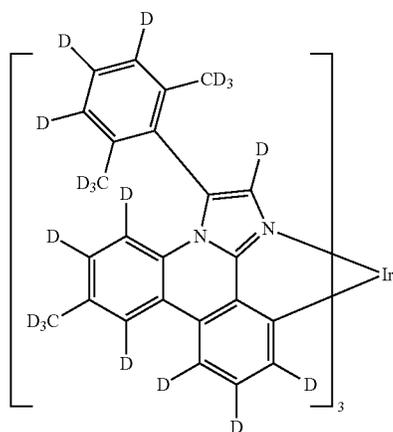
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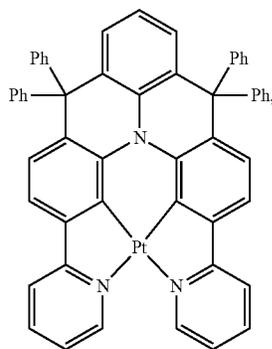


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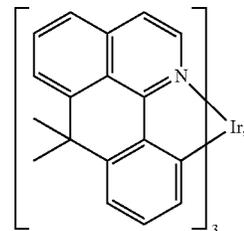
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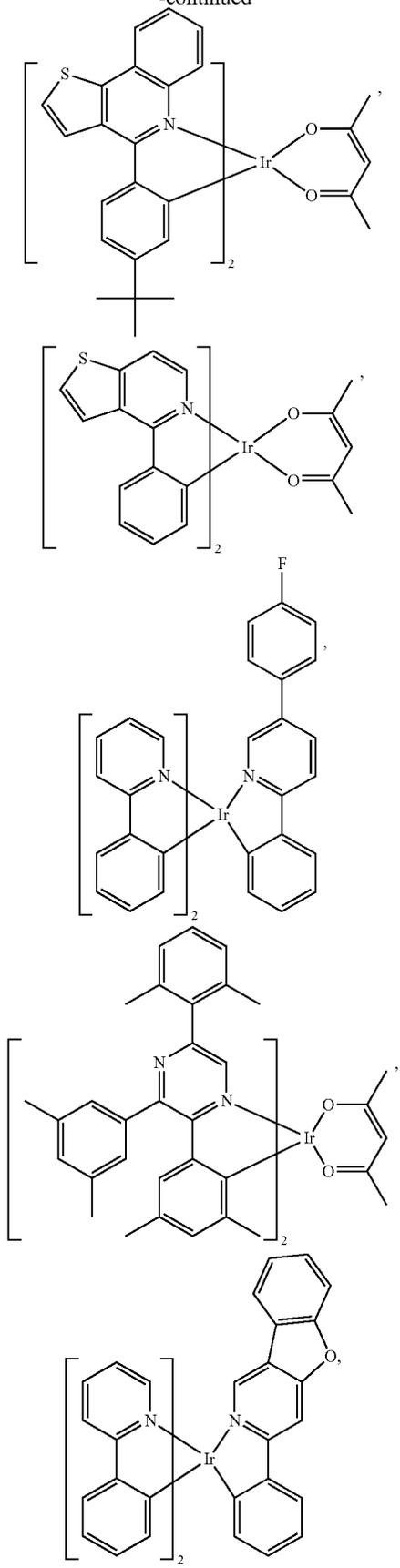
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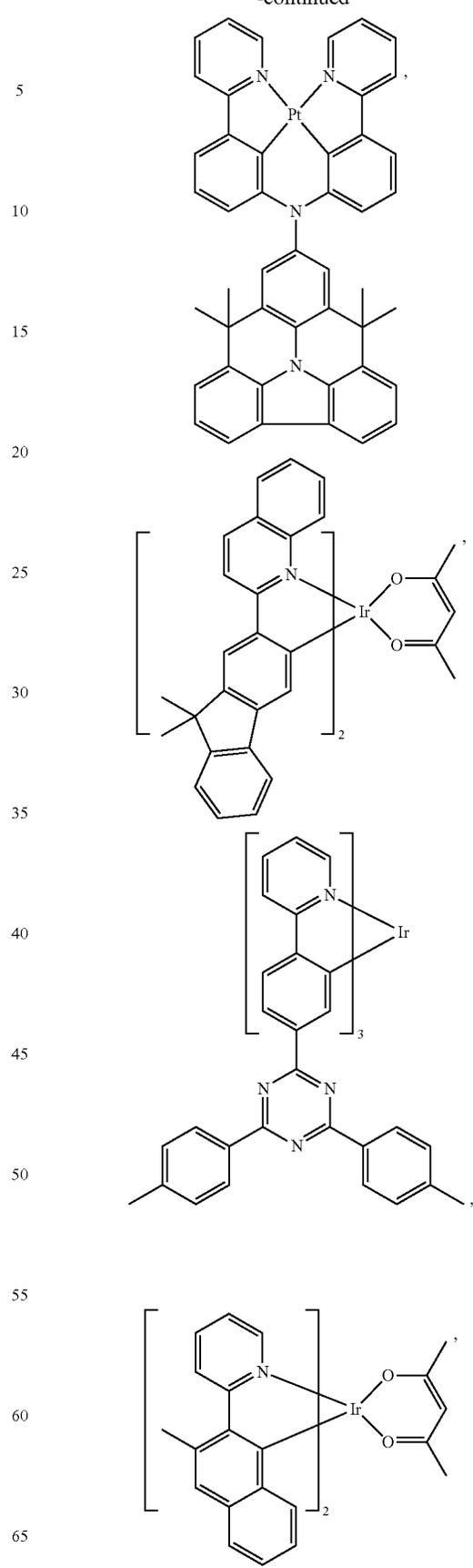
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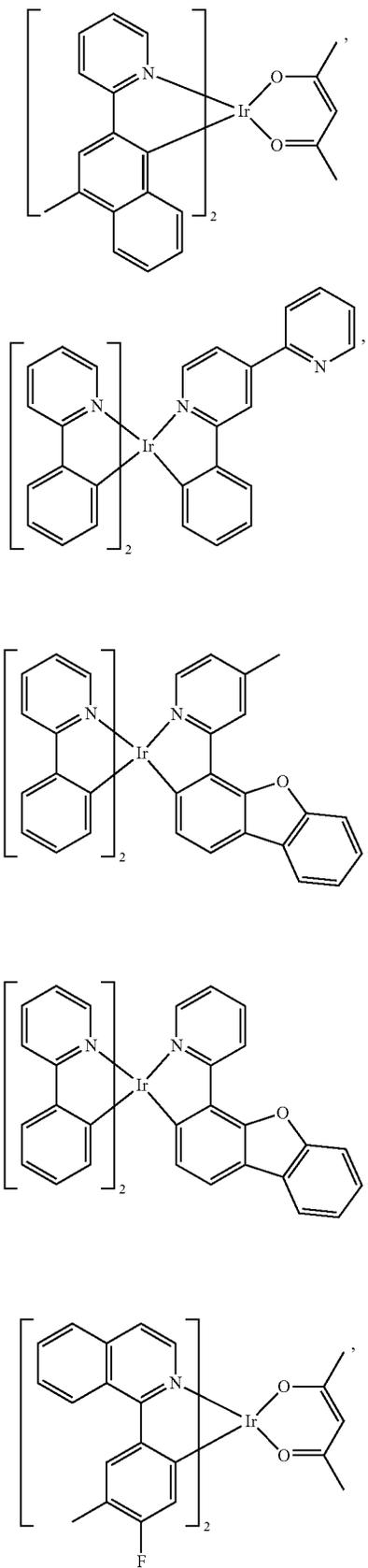
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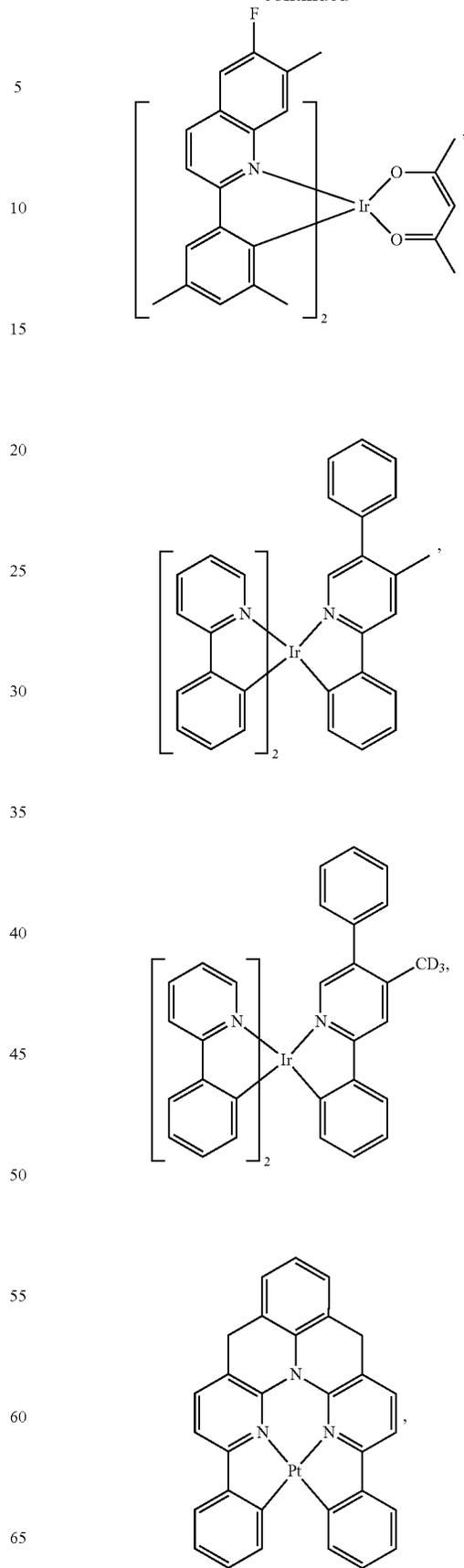
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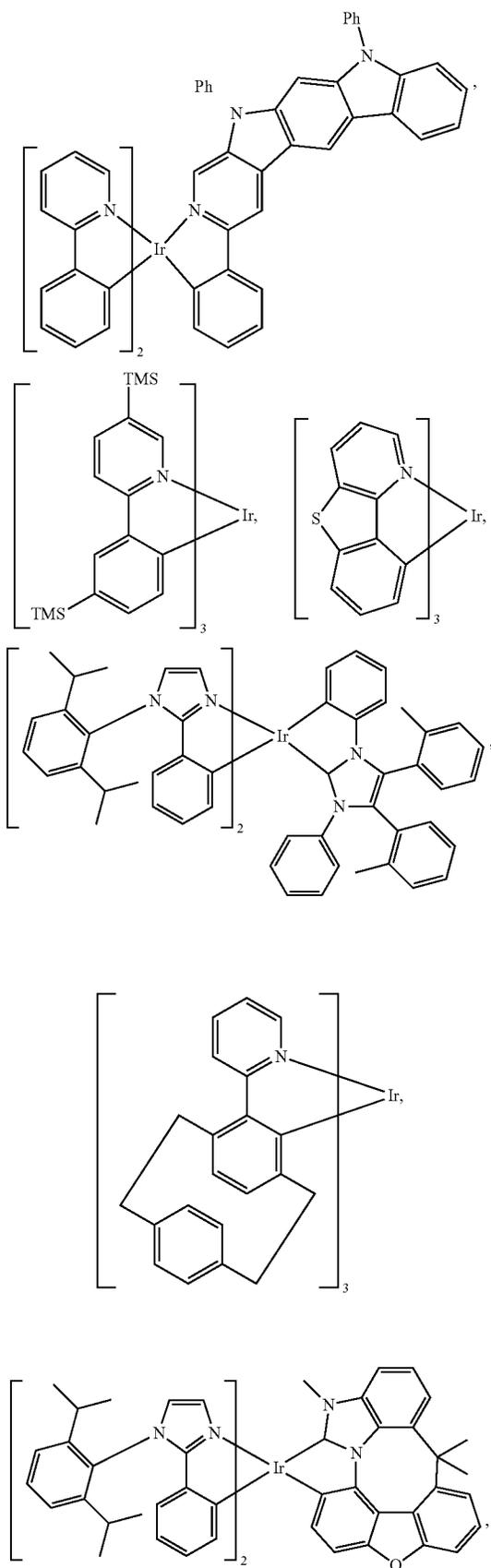
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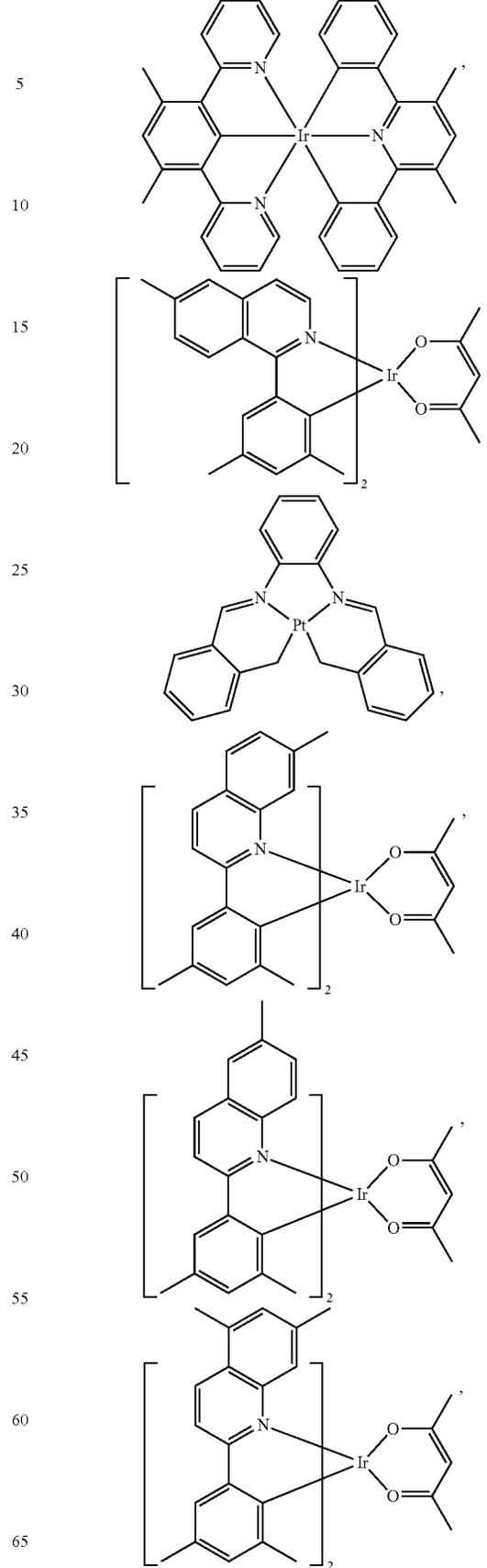
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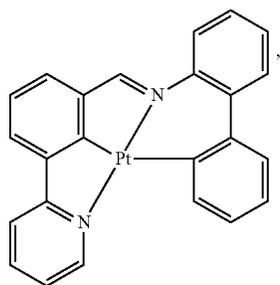
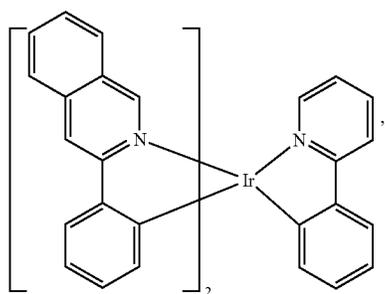
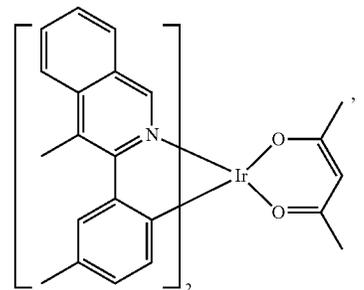
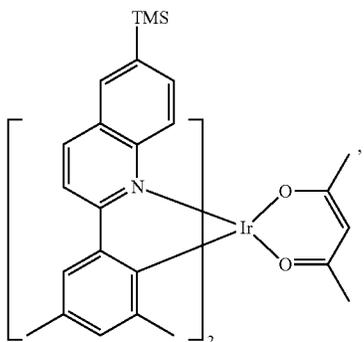
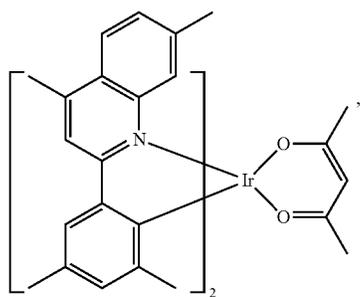
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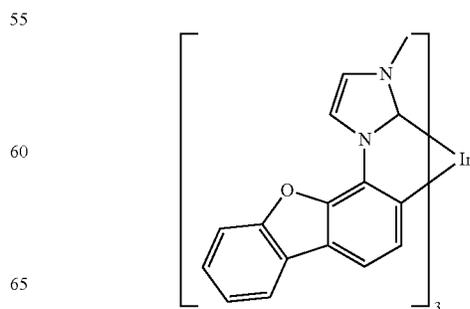
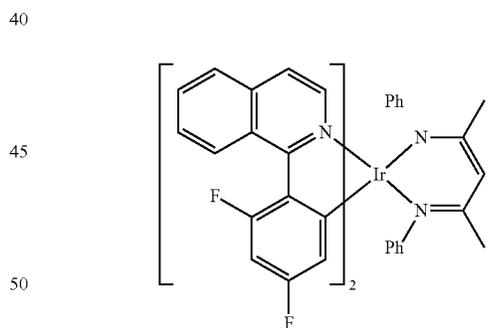
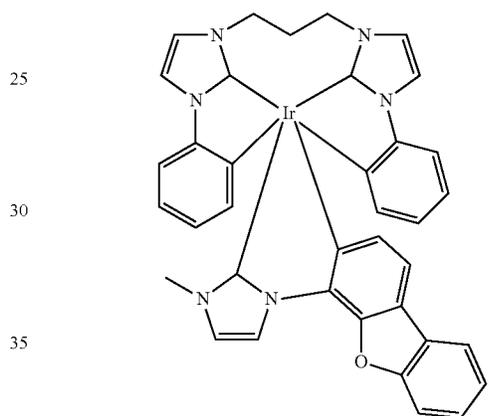
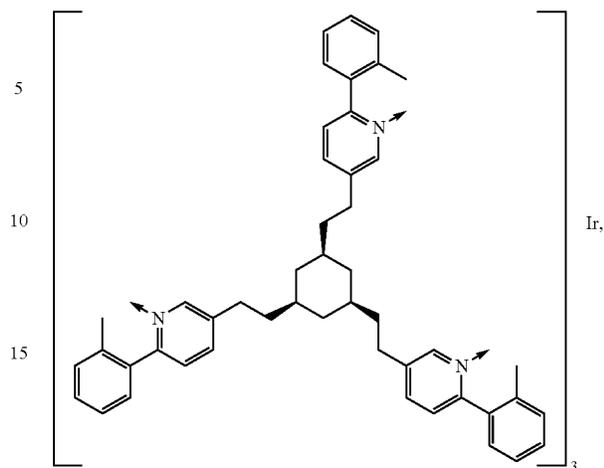
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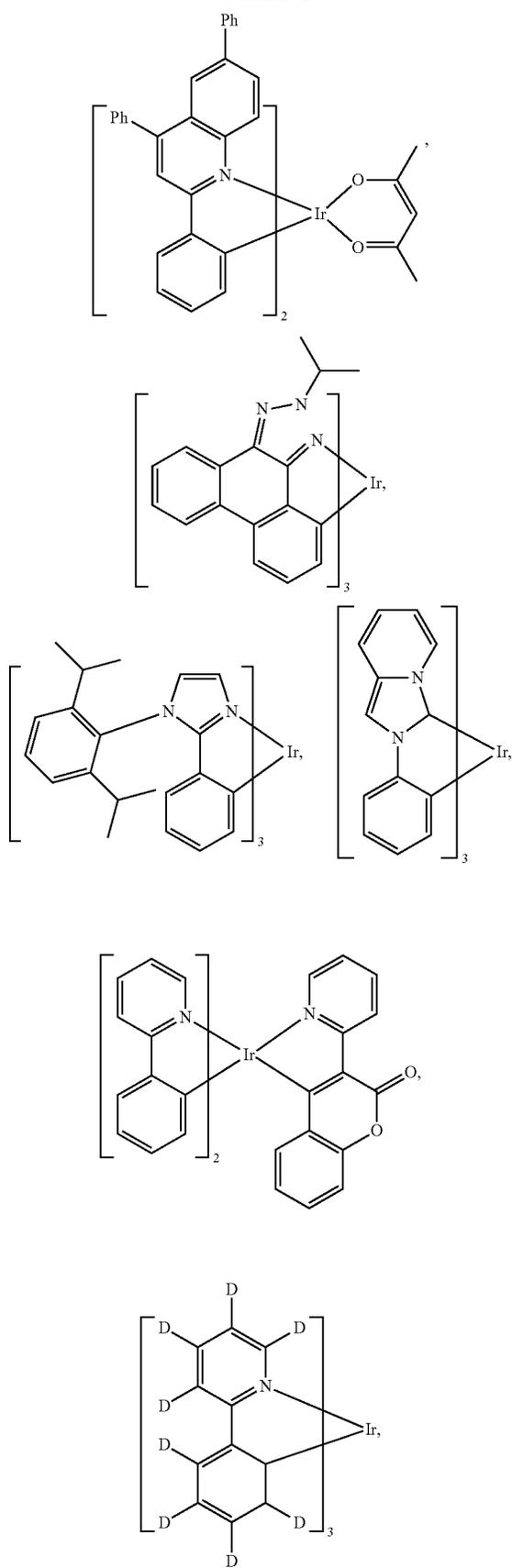
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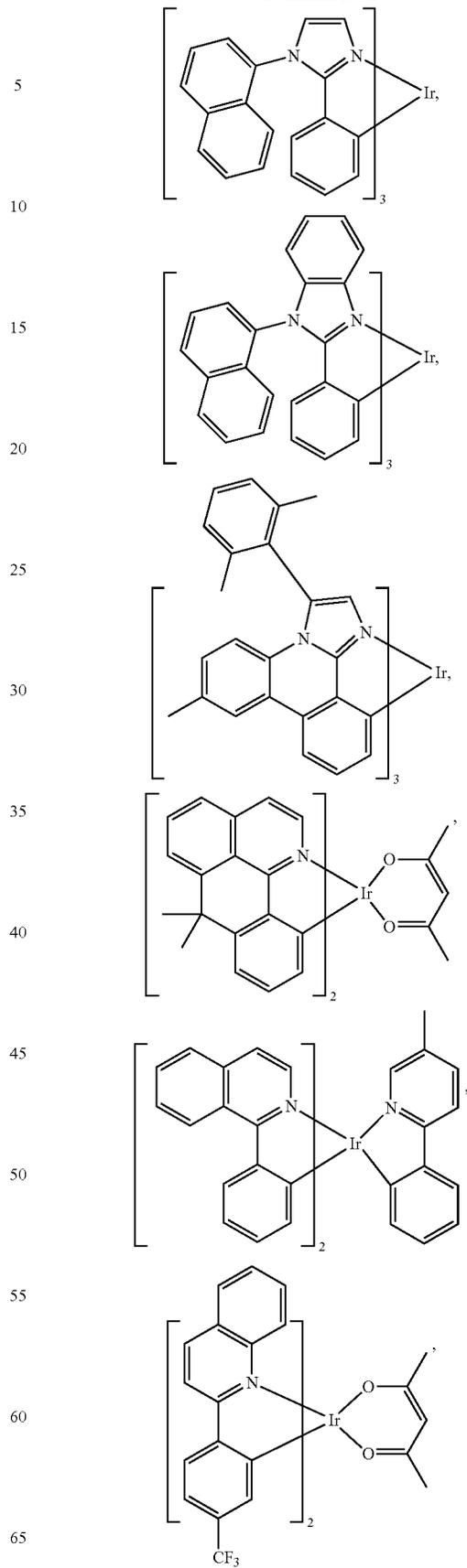
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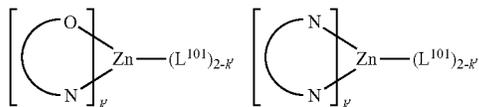
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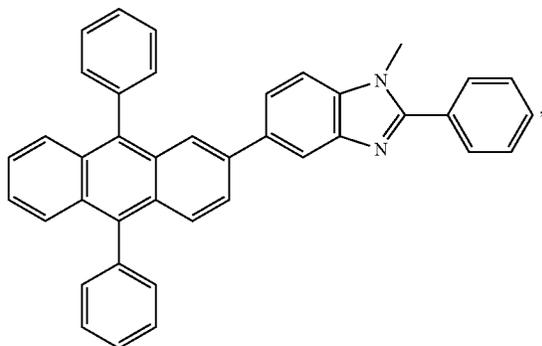
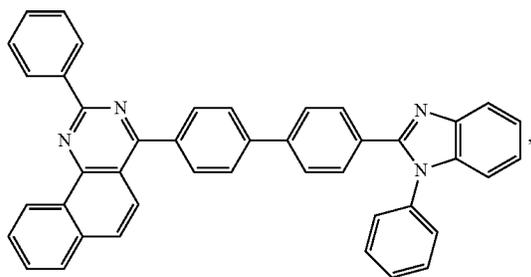
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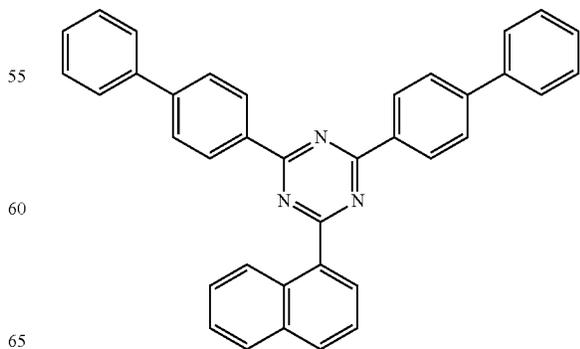
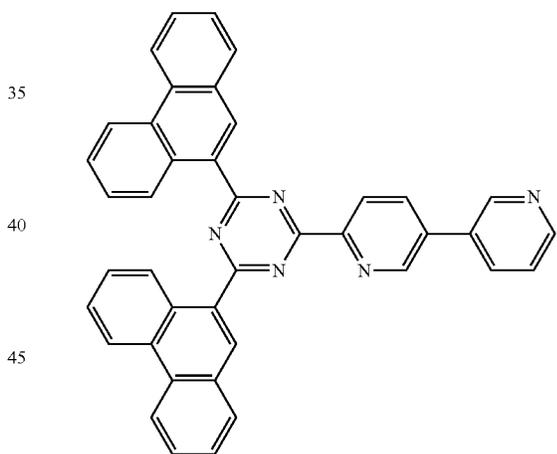
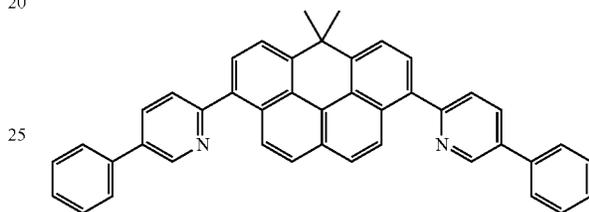
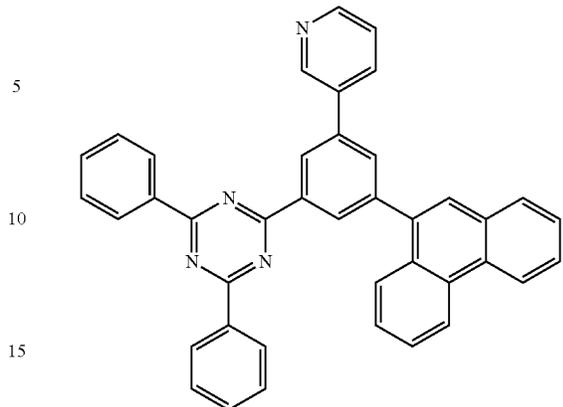
wherein (O—N) or (N—N) is a bidentate ligand, having metal coordinated to atoms O, N or N, N; L<sup>101</sup> is another ligand; k' is an integer value from 1 to the maximum number of ligands that may be attached to the metal.

Non-limiting examples of the ETL, materials that may be used in an OLED in combination with materials disclosed herein are exemplified below together with references that disclose those materials: CN103508940, EP01602648, EP01734038, EP01956007, JP2004-022334, JP2005149918, JP2005-268199, KR0117693, KR20130108183, US20040036077, US20070104977, US2007018155, US20090101870, US20090115316, US20090140637, US20090179554, US2009218940, US2010108990, US2011156017, US2011210320, US2012193612, US2012214993, US2014014925, US2014014927, US20140284580, U.S. Pat. No. 6,656,612, U.S. Pat. No. 8,415,031, WO2003060956, WO2007111263, WO2009148269, WO2010067894, WO2010072300, WO2011074770, WO2011105373, WO2013079217, WO2013145667, WO2013180376, WO2014104499, WO2014104535,



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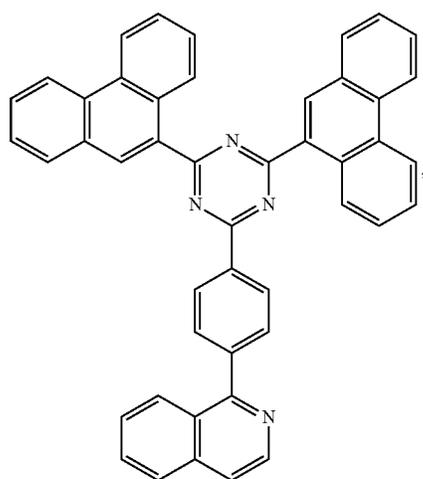
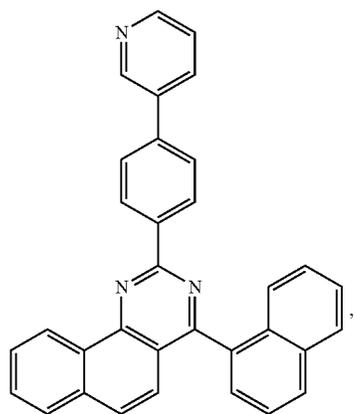
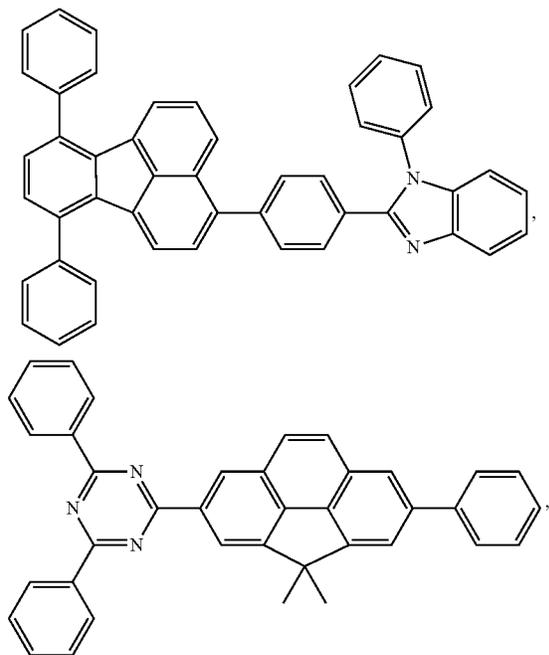
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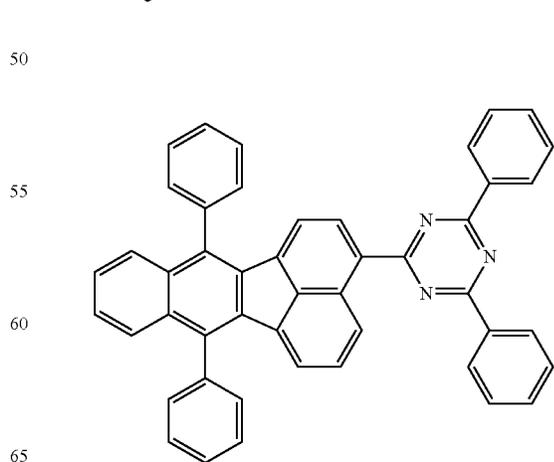
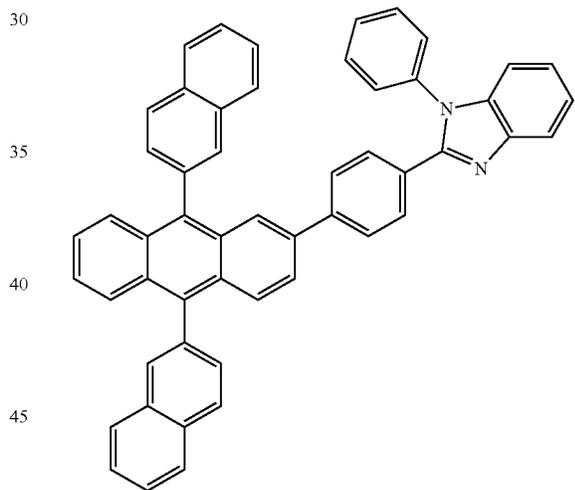
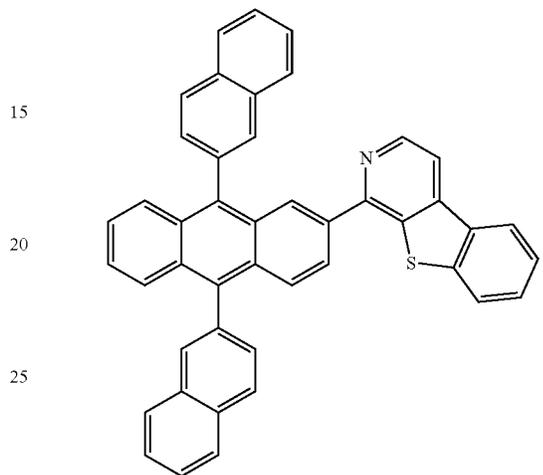
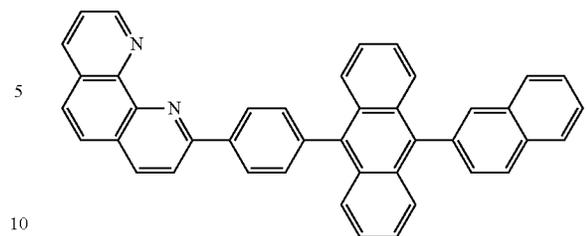
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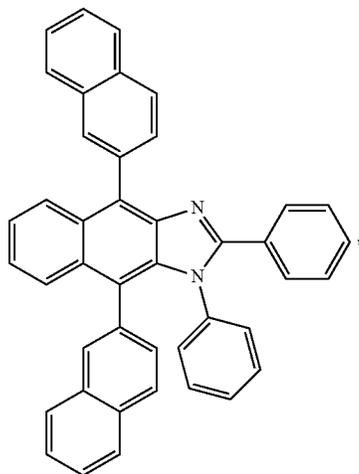
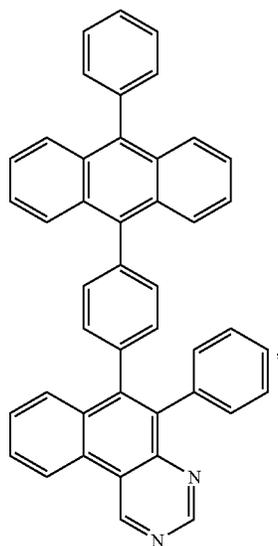
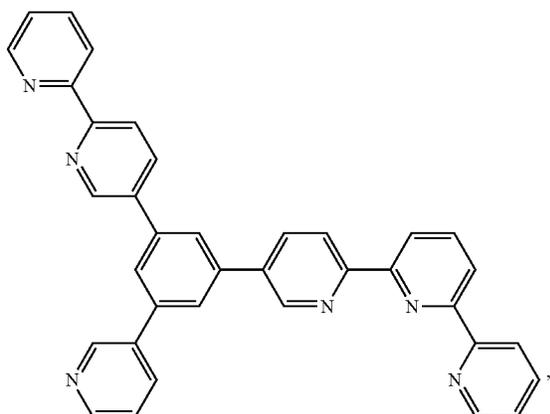
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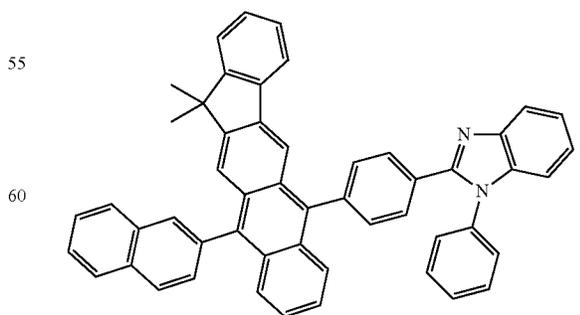
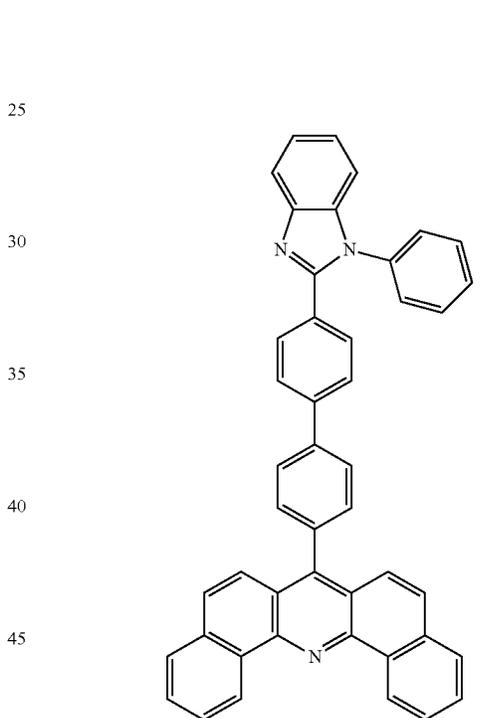
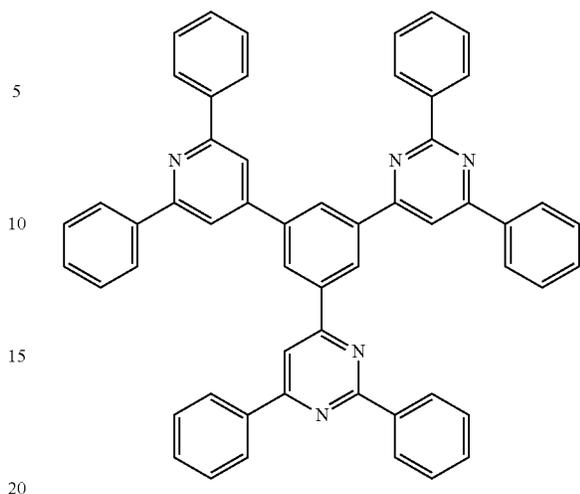
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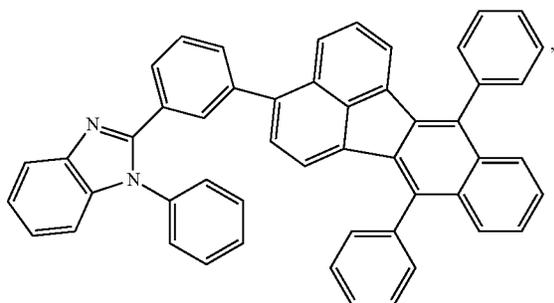
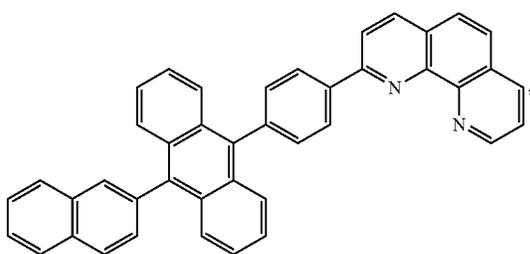
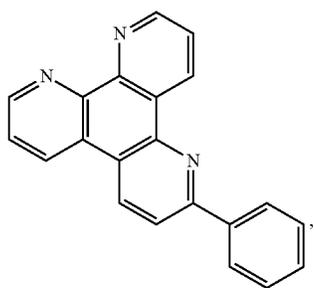
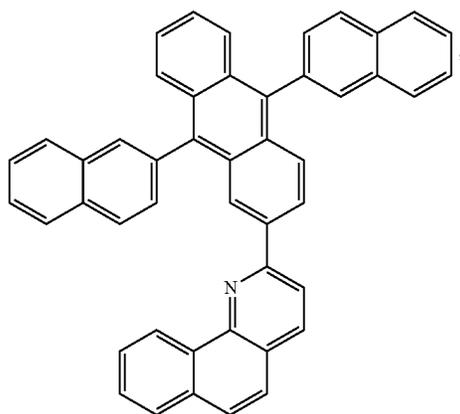
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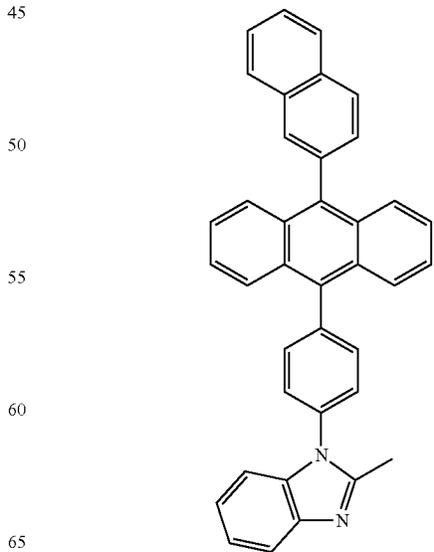
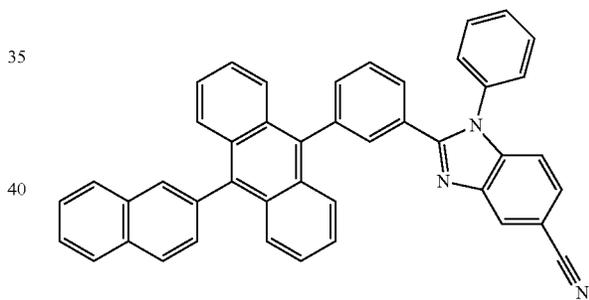
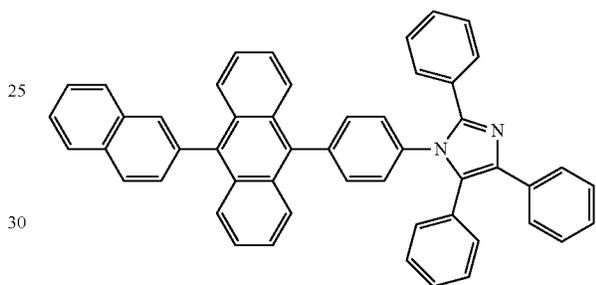
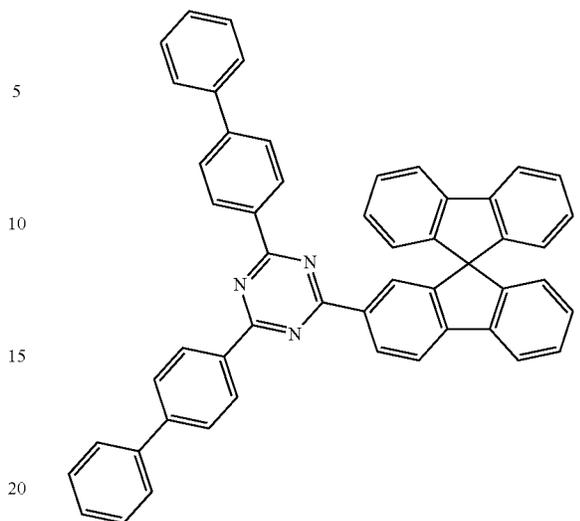
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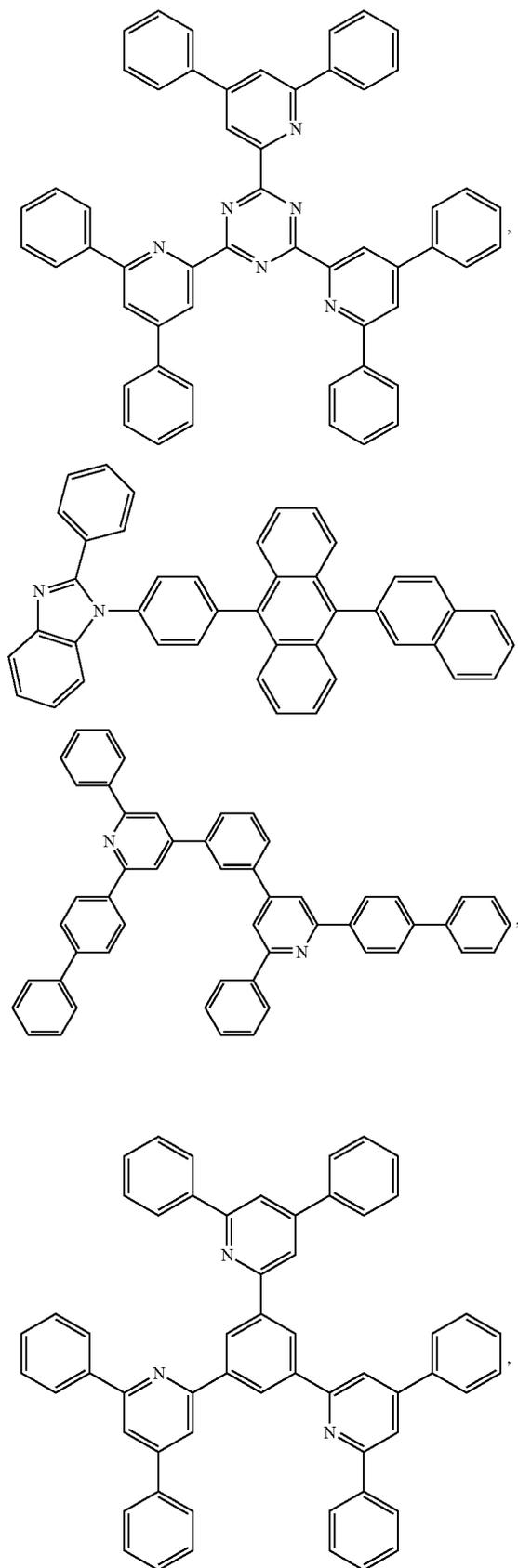
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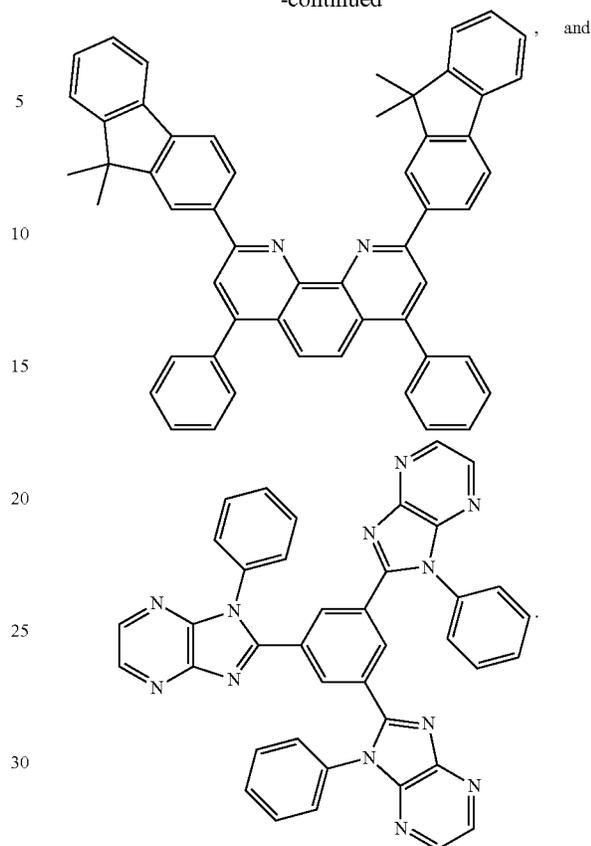
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## 35 Charge Generation Layer (CGL)

In tandem or stacked OLEDs, the CGL plays an essential role in the performance, which is composed of an n-doped layer and a p-doped layer for injection of electrons and holes, respectively. Electrons and holes are supplied from the CGL and electrodes. The consumed electrons and holes in the CGL are refilled by the electrons and holes injected from the cathode and anode, respectively; then, the bipolar currents reach a steady state gradually. Typical CGL materials include n and p conductivity dopants used in the transport layers.

In any above-mentioned compounds used in each layer of the OLED device, the hydrogen atoms can be partially or fully deuterated. Thus, any specifically listed substituent, such as, without limitation, methyl, phenyl, pyridyl, etc. encompasses undeuterated, partially deuterated, and fully deuterated versions thereof. Similarly, classes of substituents such as, without limitation, alkyl, aryl, cycloalkyl, heteroaryl, etc. also encompass undeuterated, partially deuterated, and fully deuterated versions thereof.

## Experimental

All example devices were fabricated by high vacuum ( $<10^{-7}$  Torr) thermal evaporation. The anode electrode was 750 Å of indium tin oxide (ITO). The cathode consisted of 10 Å of Liq (8-hydroxyquinoline lithium) followed by 1,000 Å of Al. All devices were encapsulated with a glass lid sealed with an epoxy resin in a nitrogen glove box ( $<1$  ppm of  $H_2O$  and  $O_2$ ) immediately after fabrication, and a moisture getter was incorporated inside the package. The organic stack of the device examples consisted of sequentially, from the ITO surface, 100 Å of HATCN as the hole injection layer (HIL); 450 Å of HTM as a hole transporting layer (HTL);

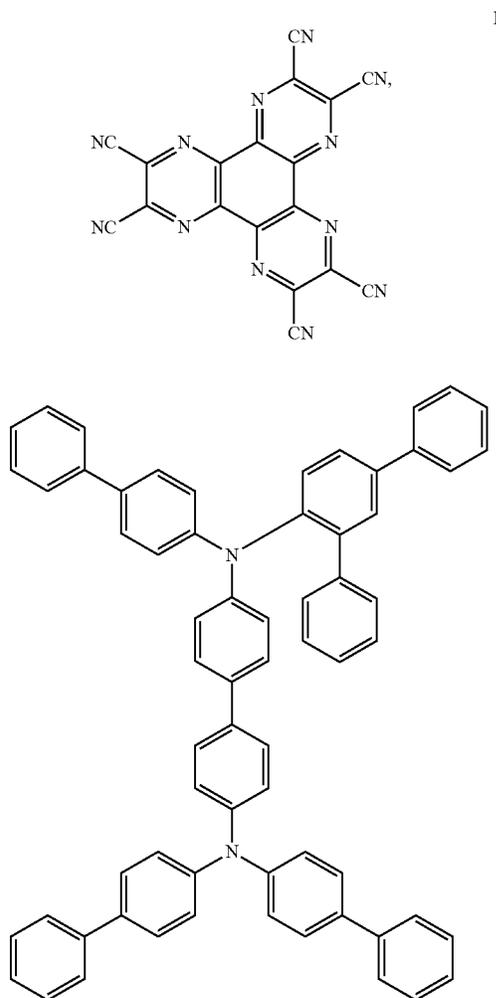
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400 Å of an emissive layer (EML) containing H-host (HH1, HH2, or HA1) 50 weight %; E-host (A1) 40 weight %; and Green Emitter (GD) 10 weight %, and 350 Å of Liq (8-hydroxyquinoline lithium) doped with 40% of ETM as the ETL. The Comparative Example devices were the same as the device examples except that Comparative E-host CC-1 was used in the EML. Table 1 shows the device layer thickness and materials.

TABLE 1

Device layer materials and thicknesses		
Layer	Material	Thickness [Å]
Anode	ITO	750
HIL	HATCN	100
HTL	HTM	450
EML	H-host:E-host 40%:GD 10%	400
ETL	Liq: ETM 40%	350
EIL	Liq	10
Cathode	Al	1000

The chemical structures of the device materials are shown below.



HAT-CN

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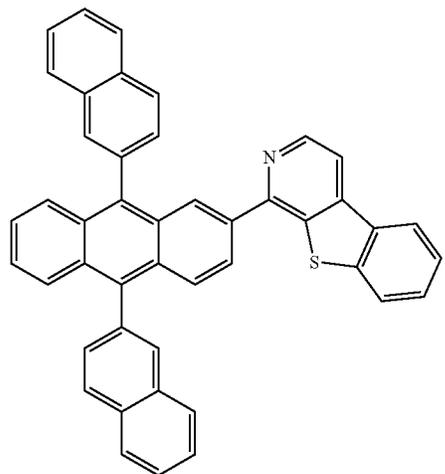
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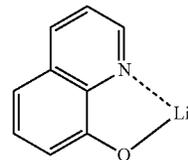
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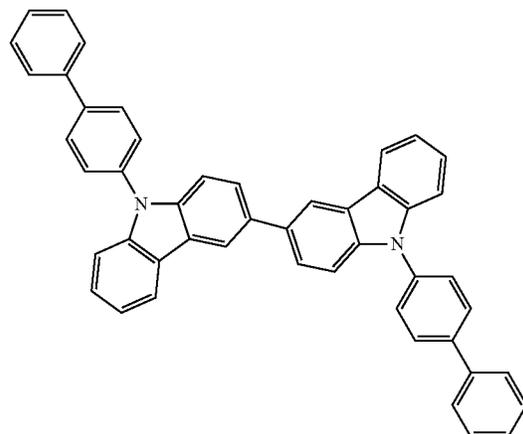


ETM

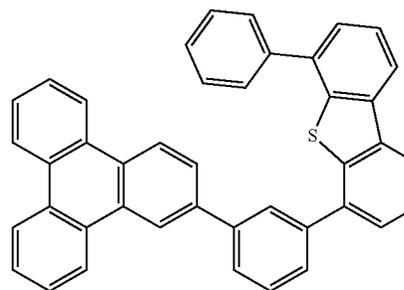


Liq

HH1



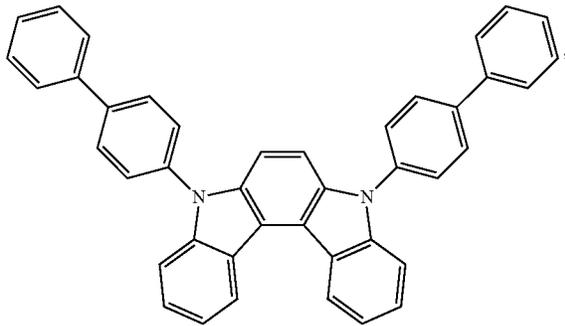
HH2



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HA67

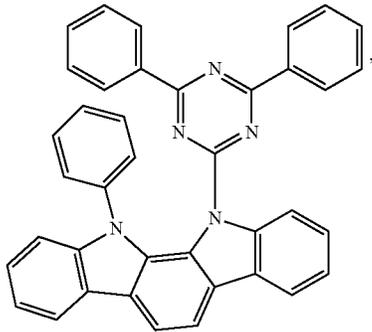


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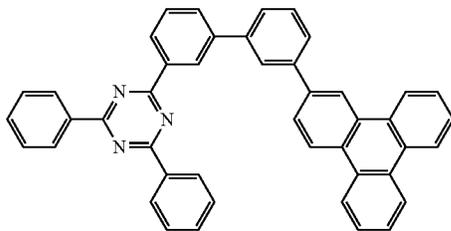
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A1



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CC1

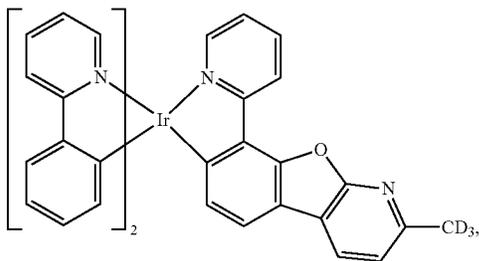
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and

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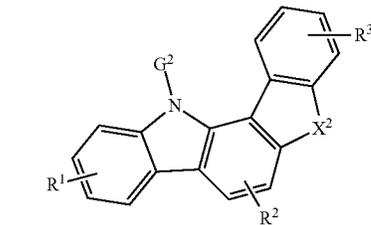
D13

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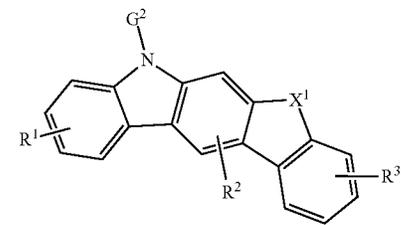


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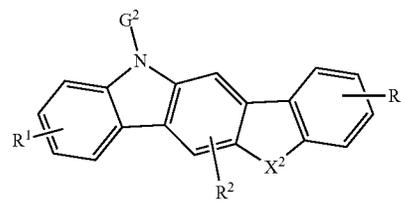
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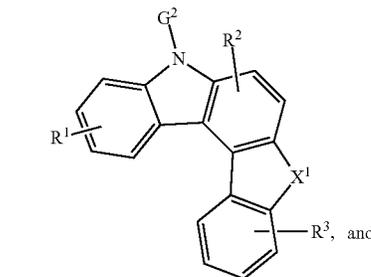
GH1



GH2



GH3



GH4

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The data in Table 2 show that inventive devices (Device 1, Device 2, and Device 3) have lower voltages, higher efficiency and longer lifetime than comparative devices (CD1, CD2, and CD3). The superior performance of the inventive devices is attributable to their use of compound A1 as the E-host, while the comparative devices have compound CC-1 as the E-host. It appears that combining the E-host A1 with dopant D13 has unique benefit to improve device performance, which is unexpected.

It is understood that the various embodiments described herein are by way of example only, and are not intended to limit the scope of the invention. For example, many of the materials and structures described herein may be substituted with other materials and structures without deviating from the spirit of the invention. The present invention as claimed may therefore include variations from the particular examples and preferred embodiments described herein, as will be apparent to one of skill in the art. It is understood that various theories as to why the invention works are not intended to be limiting.

We claim:

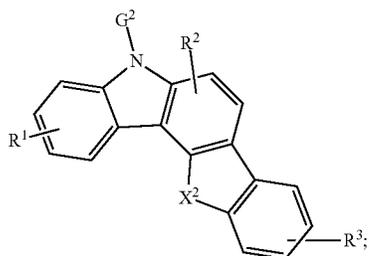
1. A composition comprising a mixture of a first compound and a second compound, wherein the first compound is selected from the group consisting of:

Table 2 below summarizes the device performance data at 1,000 nits. The lifetime ( $LT_{95}$ ) was calculated from accelerated lifestest data at 40 mA/cm<sup>2</sup> assuming an acceleration factor of 1.8, and was normalized to that of device CE-1.

Devices	H-host	E-host	Color	V [V]	PE [lm/W]	$LT_{95}$ [A.U.]
CD 1	HH1	CC-1	Green	3.4	75	100
CD 2	HH2	CC-1	Green	4.3	61	37
CD 3	HA1	CC-1	Green	3.0	93	63
Device 1	HH1	A1	Green	2.8	110	218
Device 2	HH2	A1	Green	3.1	80	185
Device 3	HA1	A1	Green	2.7	117	85

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wherein  $X^1$  and  $X^2$  are each independently selected from the group consisting of  $CR^4R^5$ , O, S and Se;

wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein (i)  $G^2$  comprises a moiety selected from the group consisting of dibenzofuran, dibenzothiophene, dibenzoselenophene, fluorene, triphenylene, and combinations thereof, or

(ii)  $G^2$  comprises a moiety selected from the group consisting of phenanthroline, azadibenzofuran, azadibenzothiophene, azadibenzoselenophene, azafluorene, aza-triphenylene, and combinations thereof;

wherein  $R^2$ ,  $R^3$ ,  $R^4$ , and  $R^5$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein any two adjacent substituents can optionally join or fuse into a ring;

wherein at least one of option (a) or option (b) is true:

(a)  $X^1$  or  $X^2$  is present and represents Se;

(b)(1)(i) the first compound has the structure of GH2 or GH3, or (1)(ii) the first compound has a structure of GH1, GH4, or GH5, and two  $R^2$  are not joined to form a ring, and

(2) at least one of  $R^1$  and  $R^3$  is unsubstituted, and

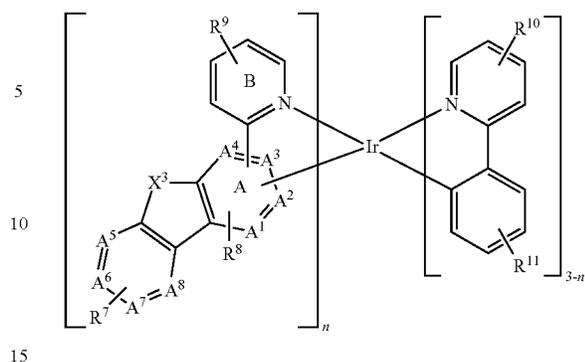
(3)  $G^2$  is selected from the group consisting of dibenzoselenophene, phenanthroline, azadibenzofuran, azadibenzoselenophene, azafluorene, and combinations thereof;

with the proviso that none of  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ , or  $R^5$  is triphenylene;

wherein the second compound has a formula  $Ir(L_A)_n(L_B)_{3-n}$ , and having the structure according to Formula II

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GH5



wherein each  $A^1$ ,  $A^2$ ,  $A^3$ ,  $A^4$ ,  $A^5$ ,  $A^6$ ,  $A^7$ , and  $A^8$  comprise carbon or nitrogen;

wherein ring B is bonded to ring A through a C—C bond; wherein the iridium is bonded to ring A through a Ir—C bond;

wherein  $X^3$  is selected from a group consisting of O, S and Se;

wherein  $R^7$  to  $R^{11}$  each independently represent mono to the possible maximum number of substitution, or no substitution;

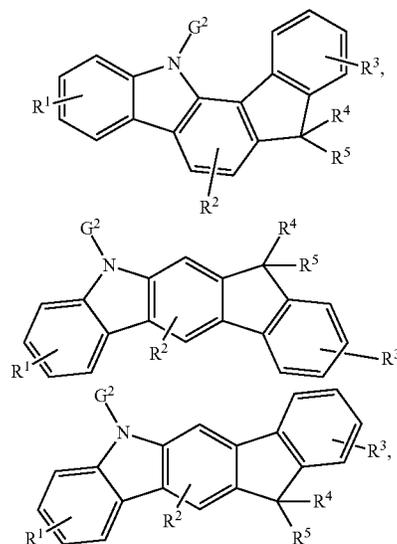
wherein  $R^7$  to  $R^{11}$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and

wherein any two adjacent substituents can optionally join or fuse into a ring; and

wherein  $n$  is an integer from 1 to 3.

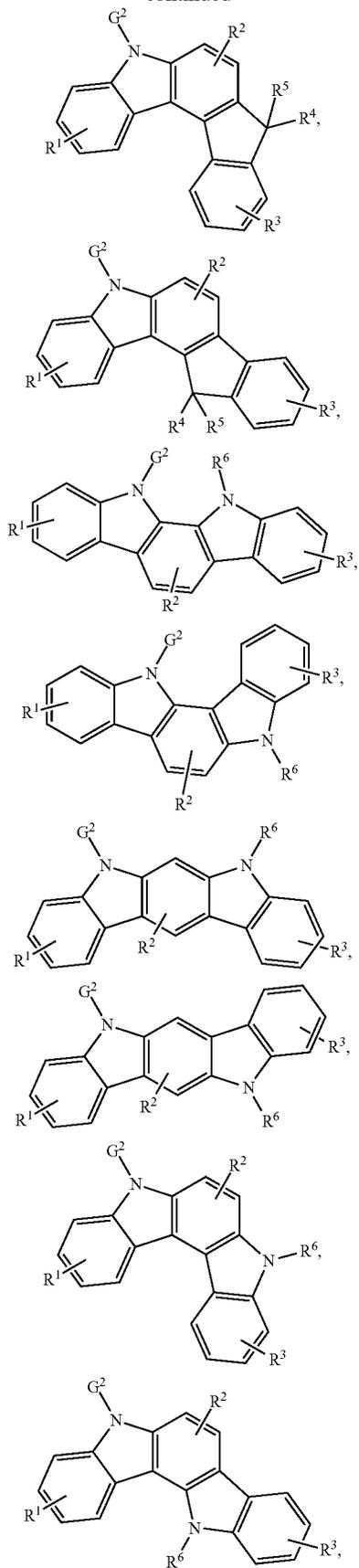
2. The composition of claim 1, wherein  $G^2$  is further substituted.

3. The composition of claim 1, wherein the first compound is selected from the group consisting of:



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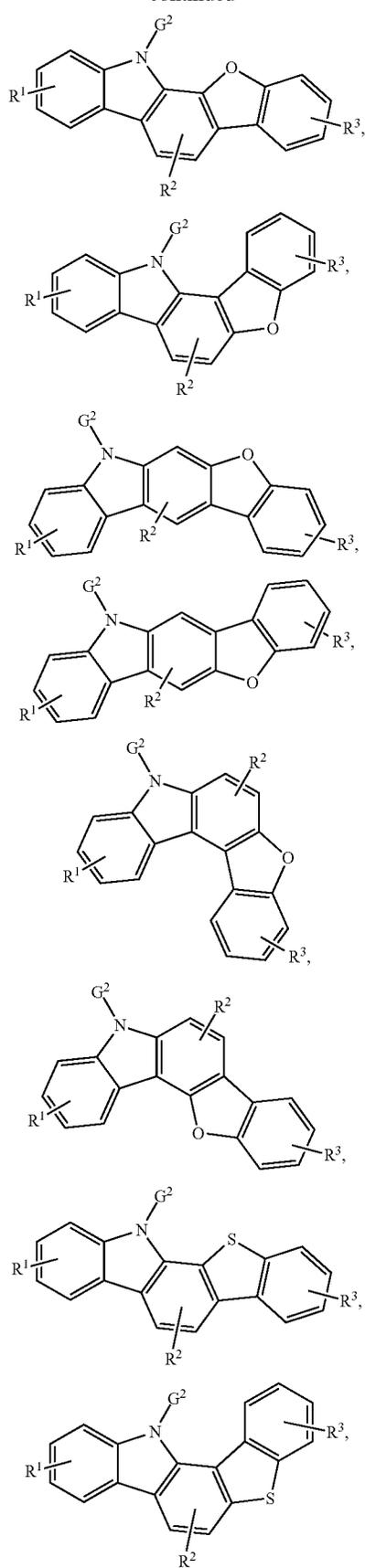
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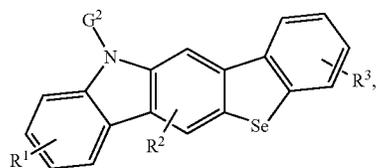
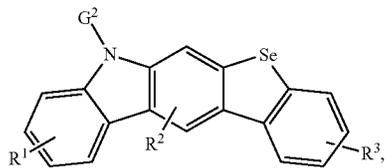
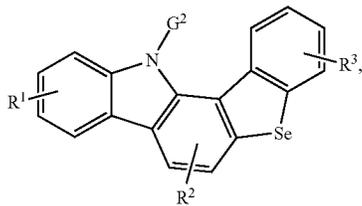
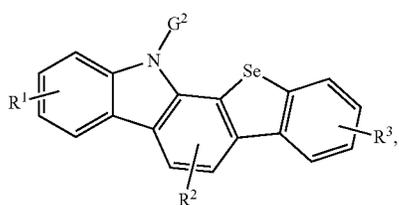
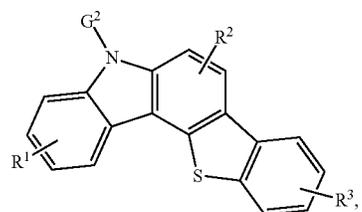
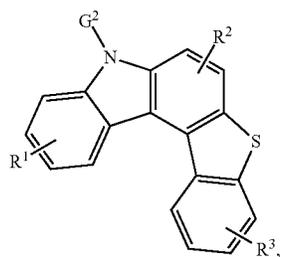
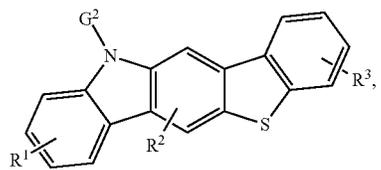
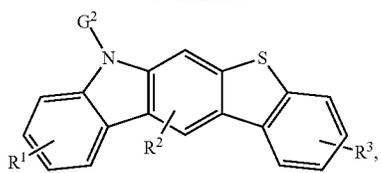
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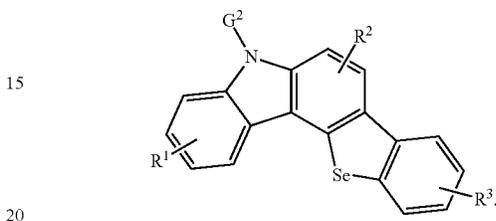
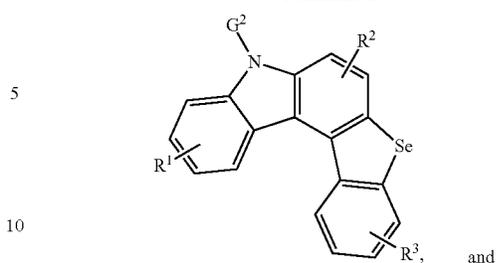
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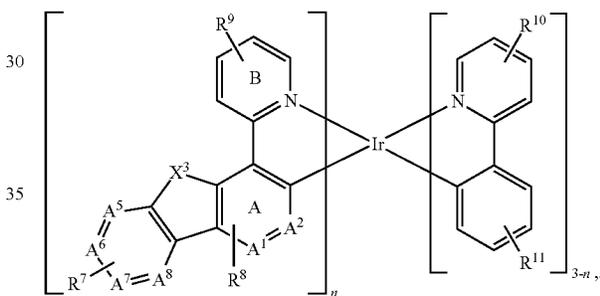
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4. The composition of claim 1, wherein the second compound has the formula:

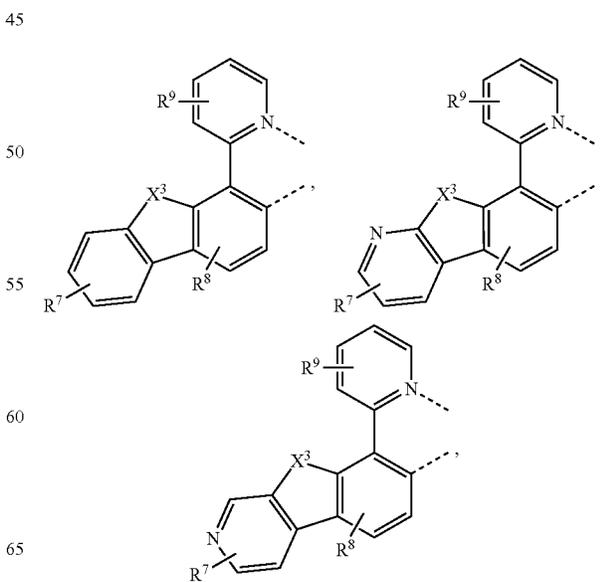
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Formula III



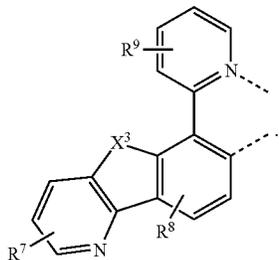
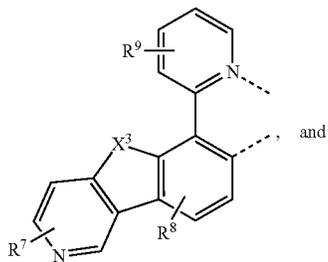
5. The composition of claim 1, wherein X³ is O.

6. The composition of claim 1, wherein L<sub>A</sub> is selected from the group consisting of:

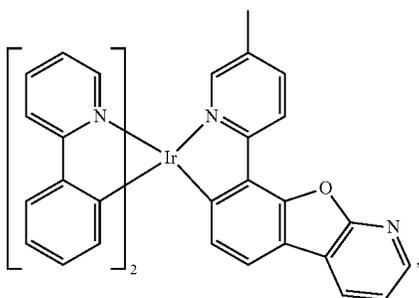
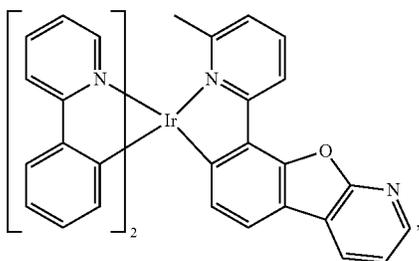
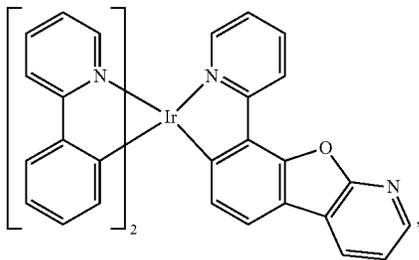


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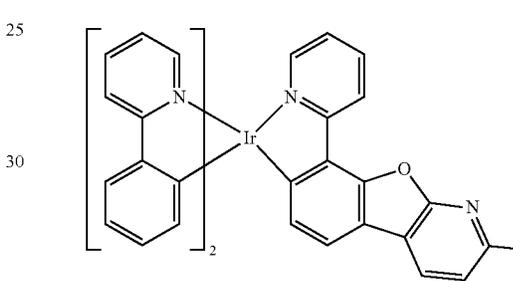
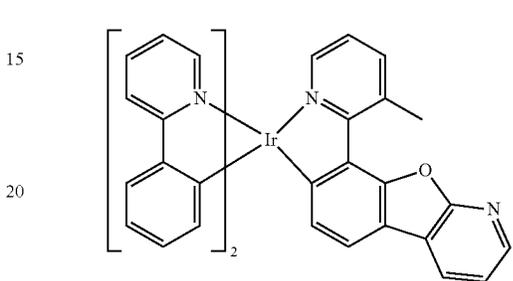
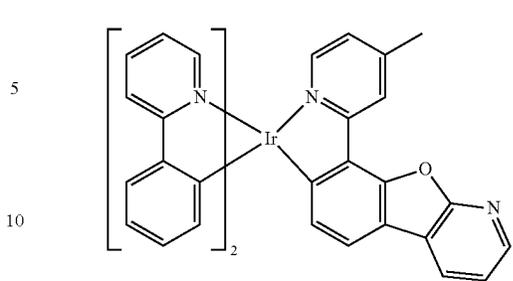


7. The composition of claim 1, wherein the second compound is selected from the group consisting of:



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D1

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D2

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D3

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D4

D5

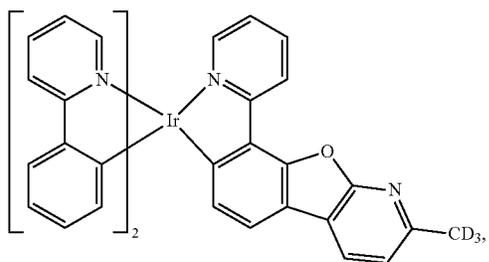
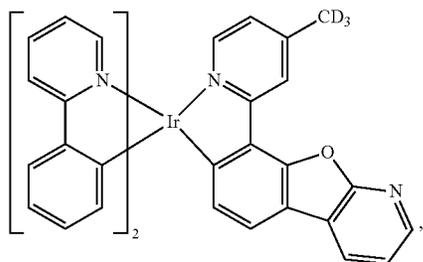
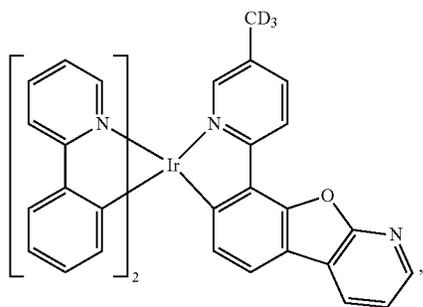
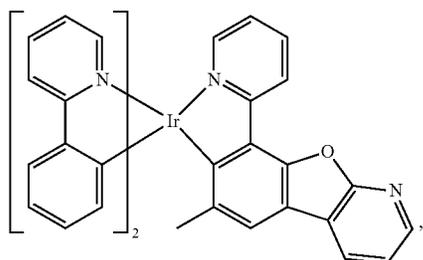
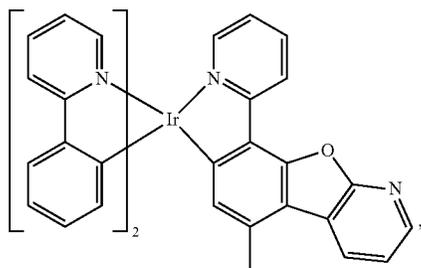
D6

D7

D8

**255**

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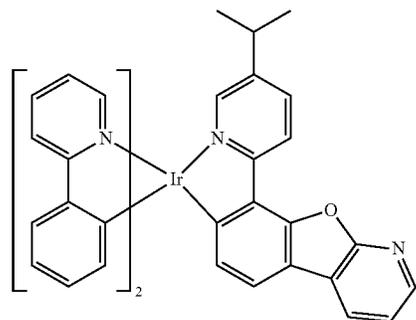


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D9

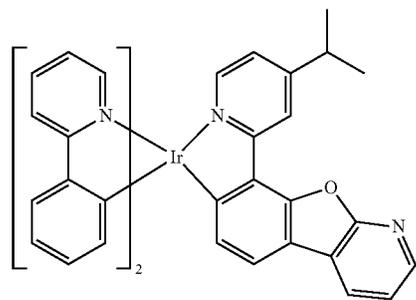
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D14

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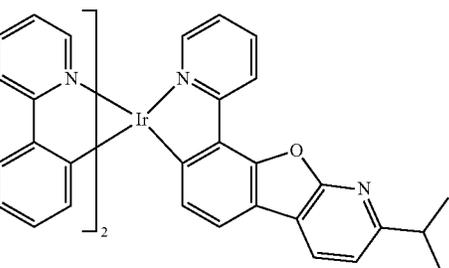
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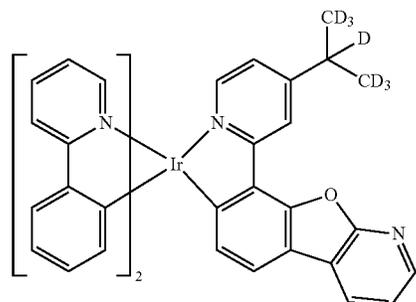


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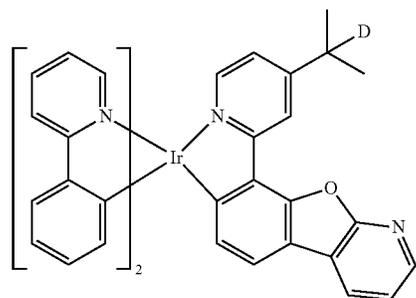


D17

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D13

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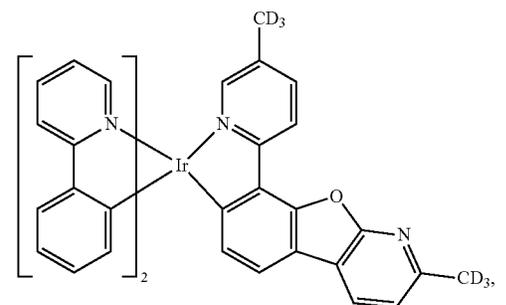
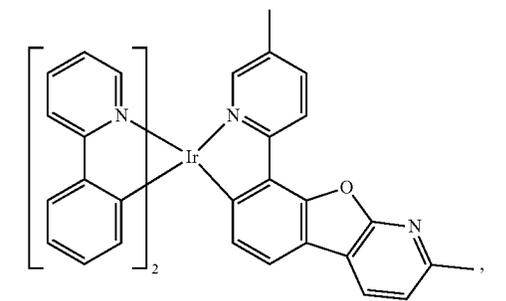
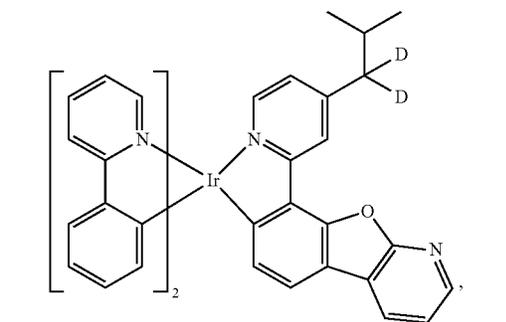
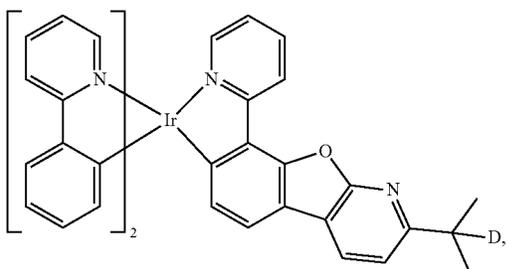
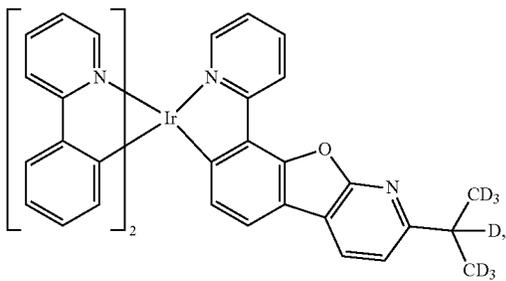


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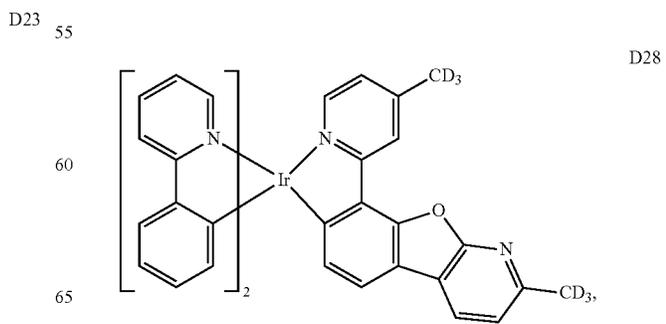
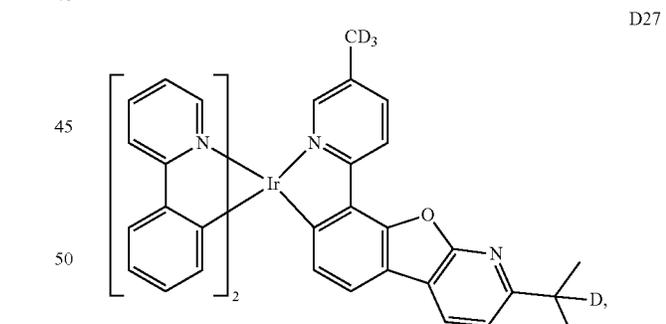
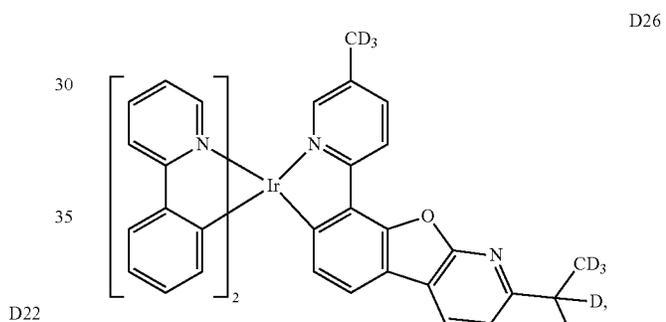
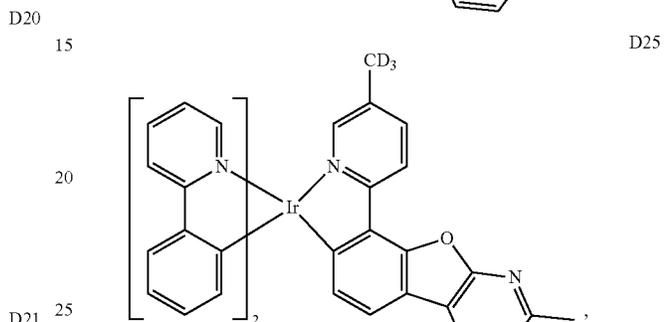
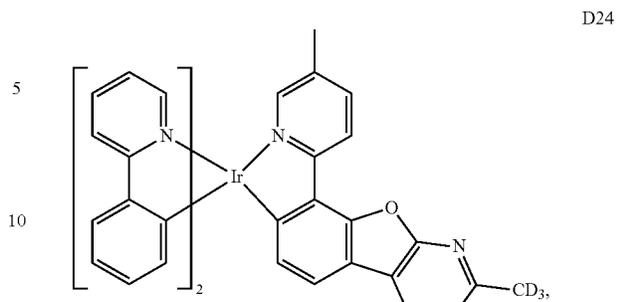
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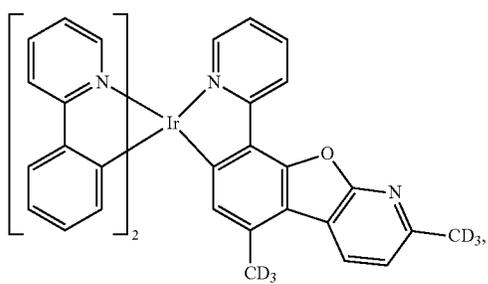
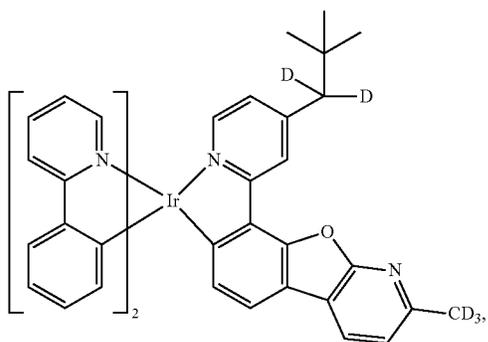
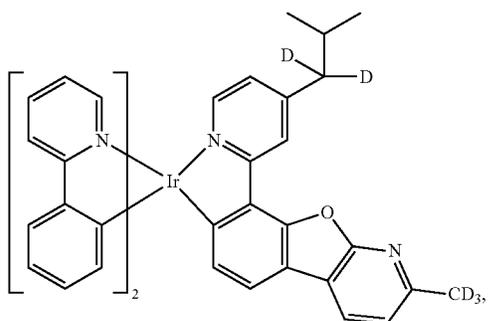
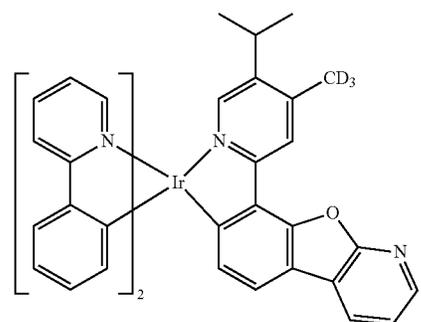
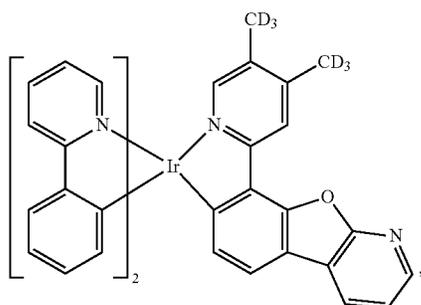


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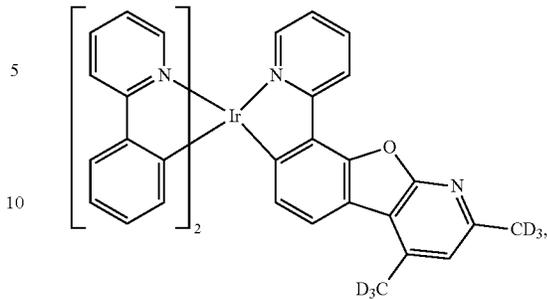
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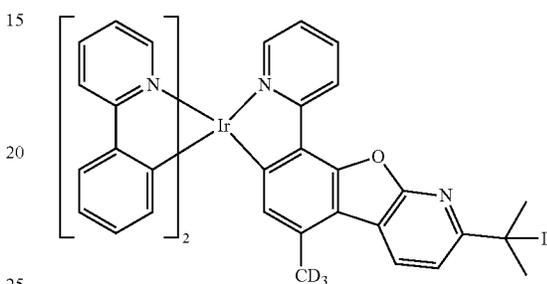
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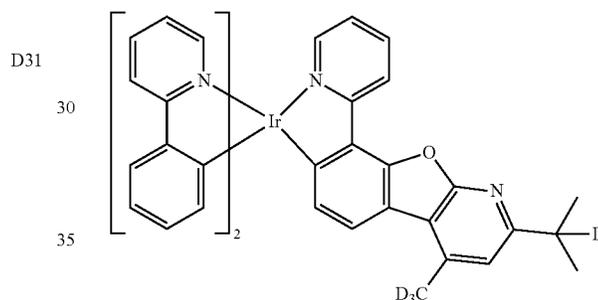
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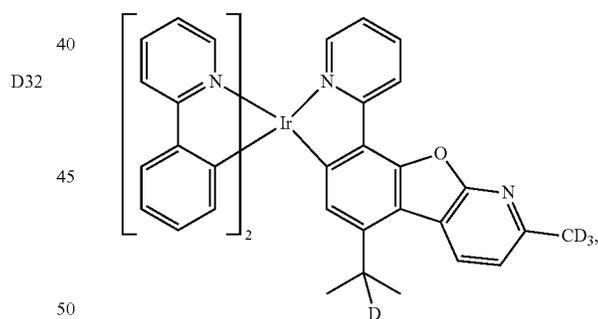
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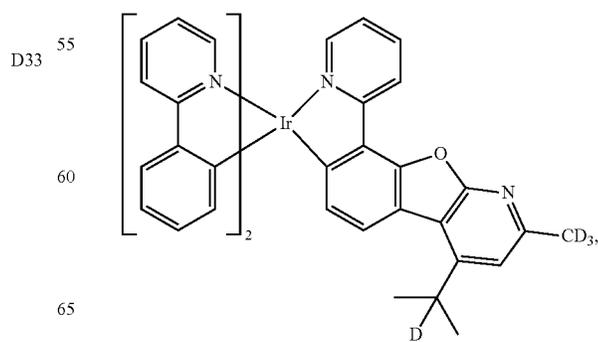
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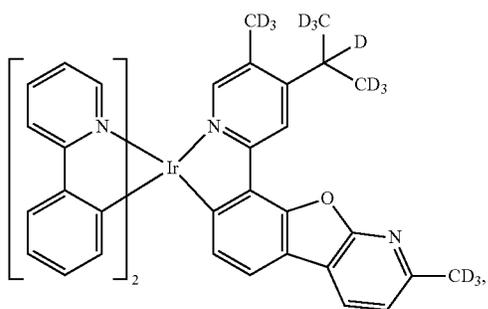
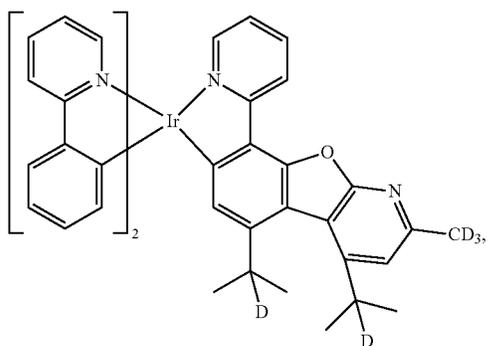
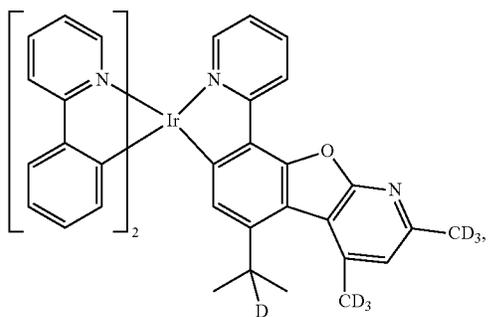
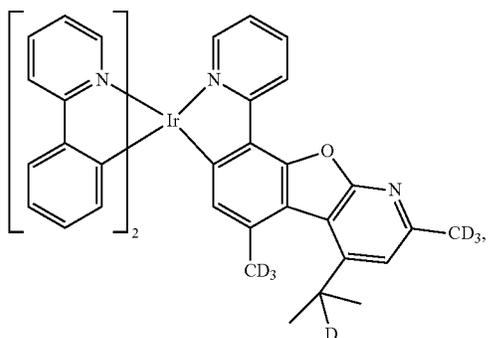
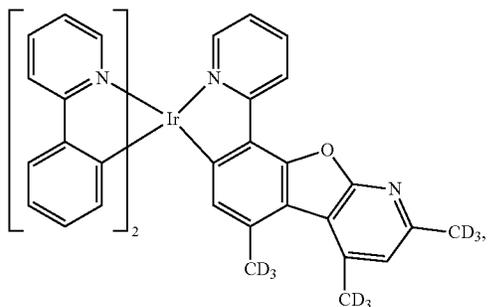


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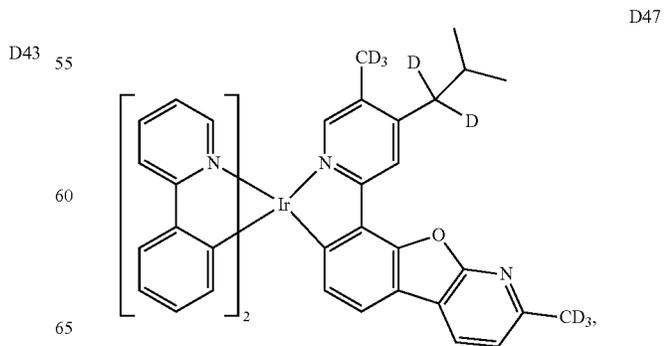
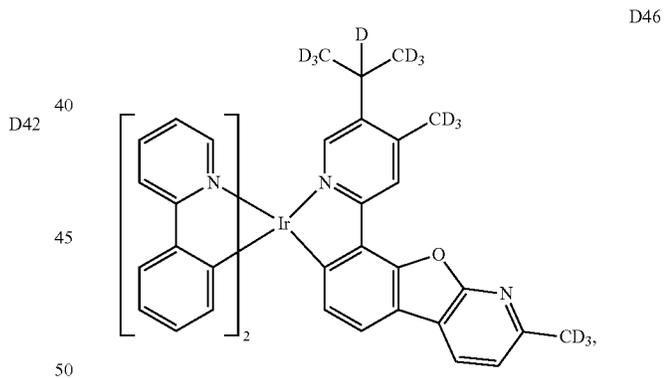
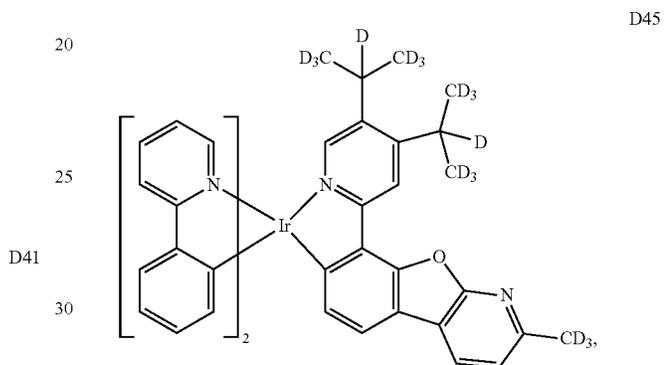
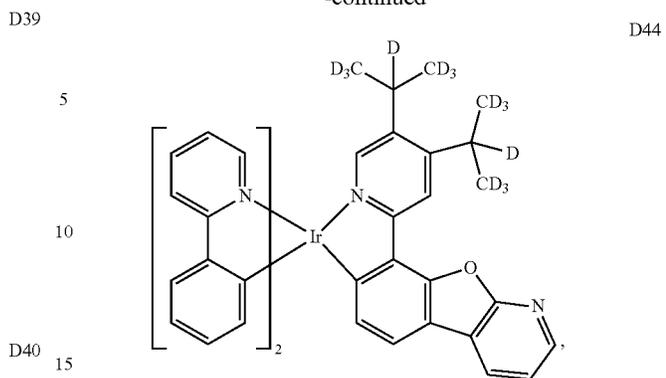


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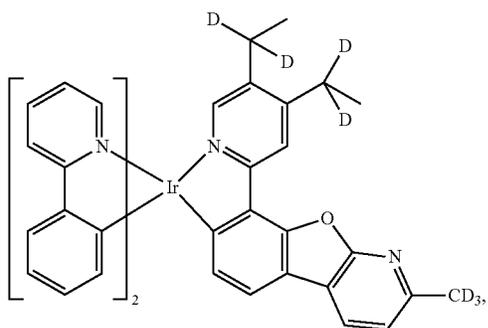


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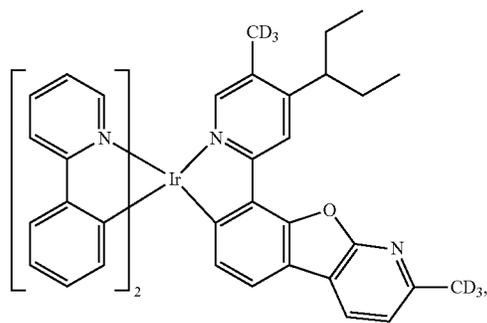


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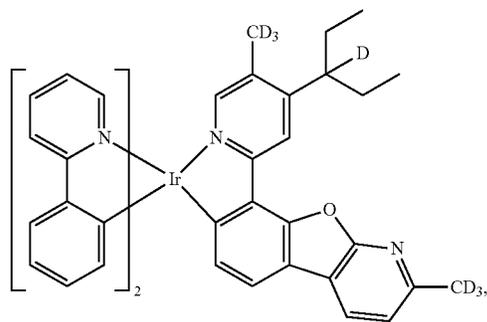
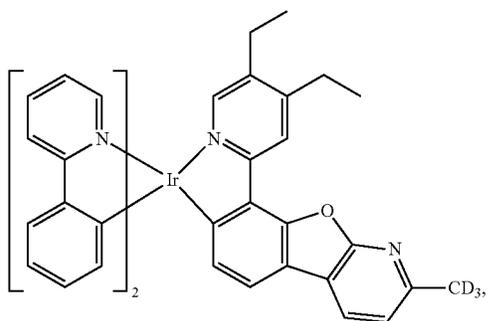
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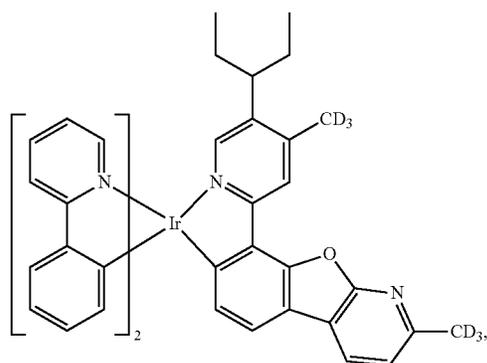
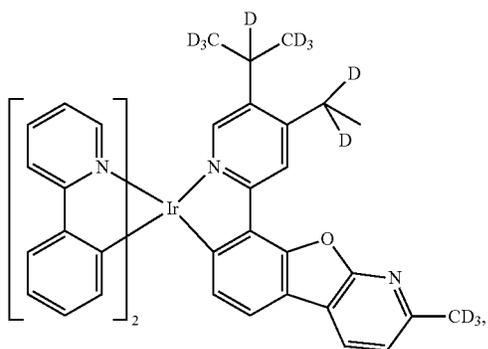
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D54

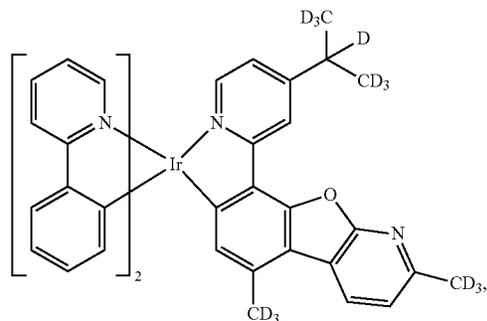
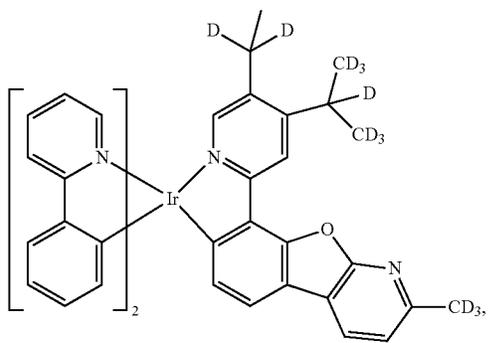
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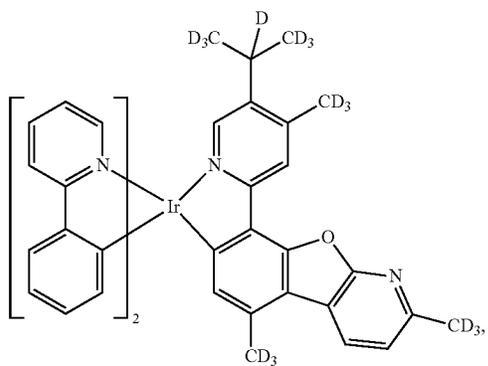
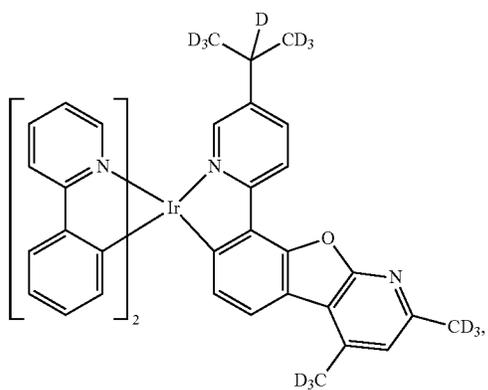
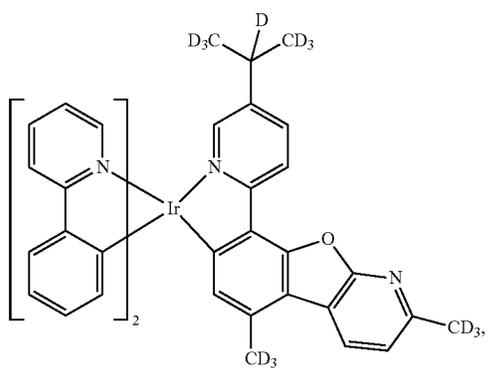
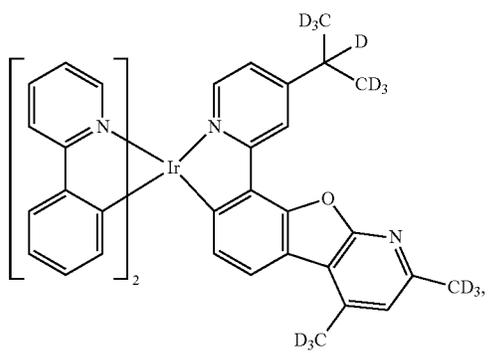


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**265**  
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**266**  
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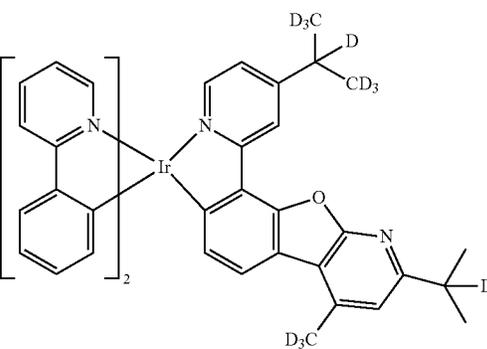
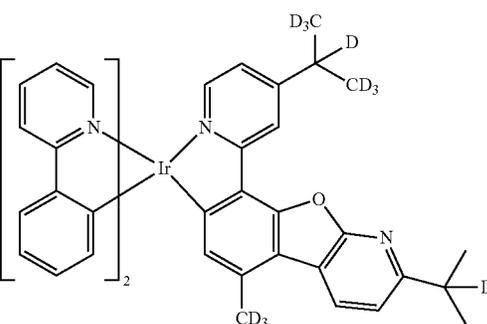
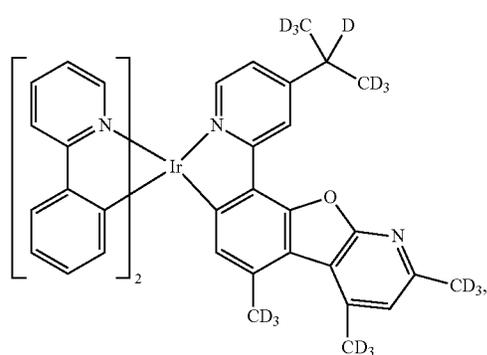
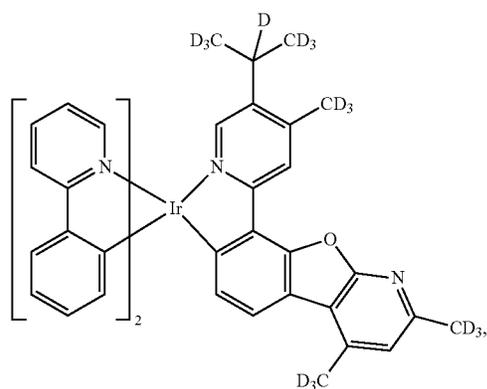
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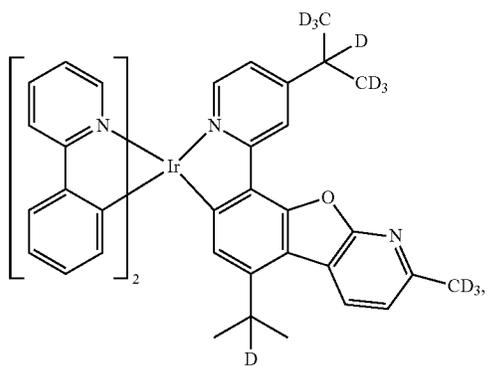
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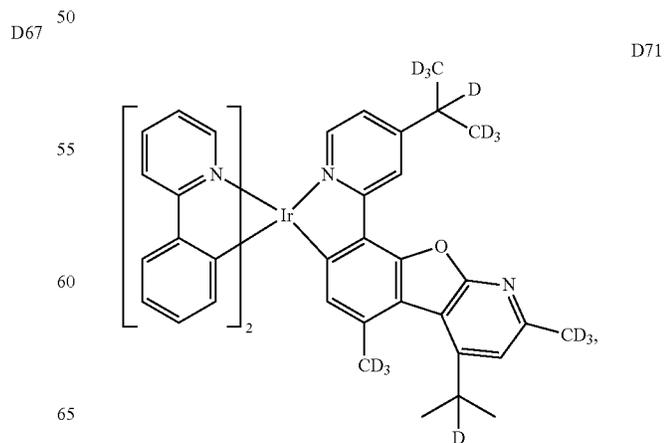
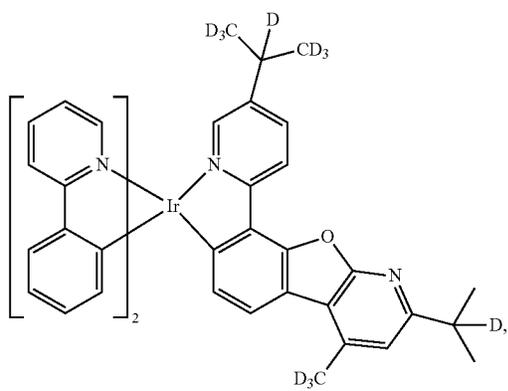
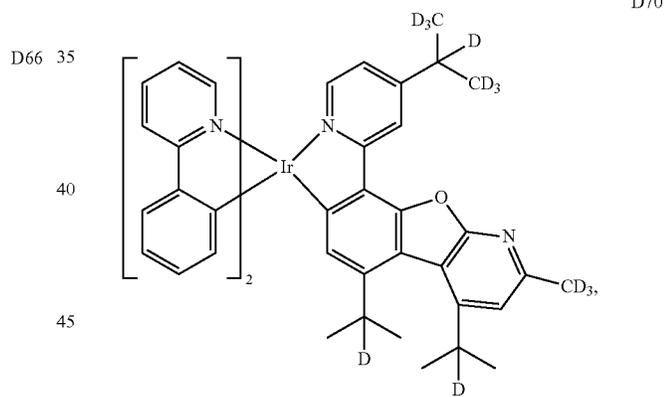
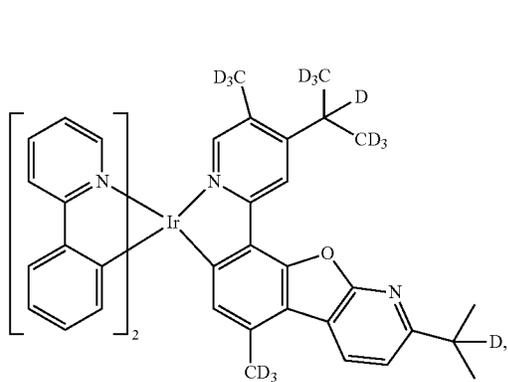
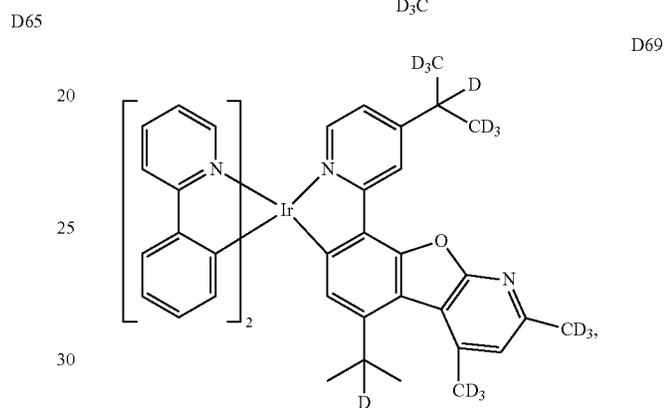
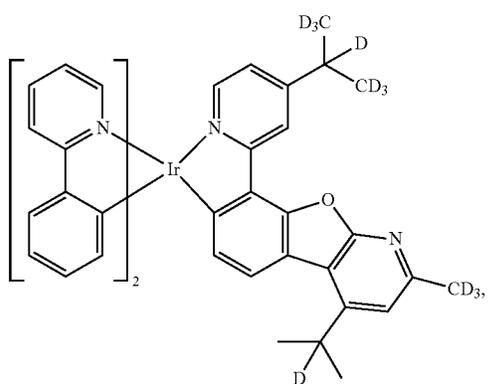
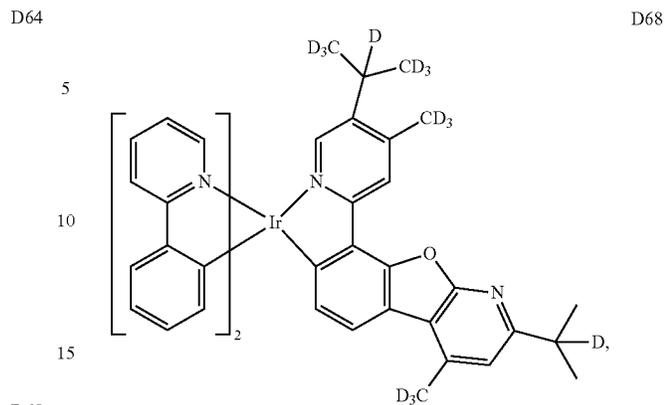
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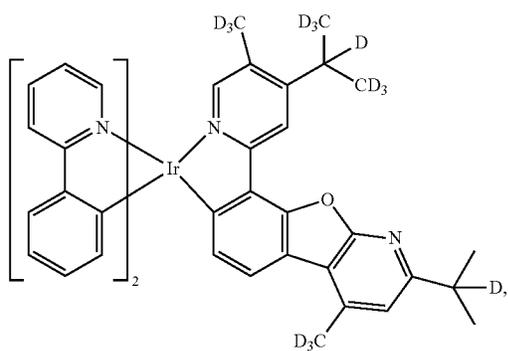


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**269**

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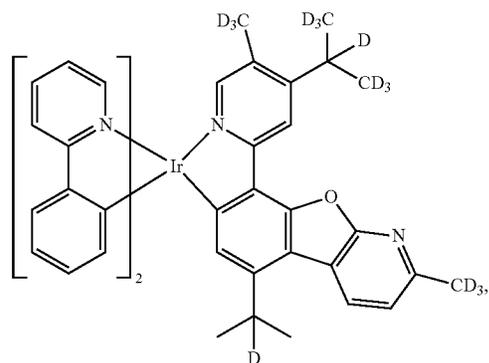
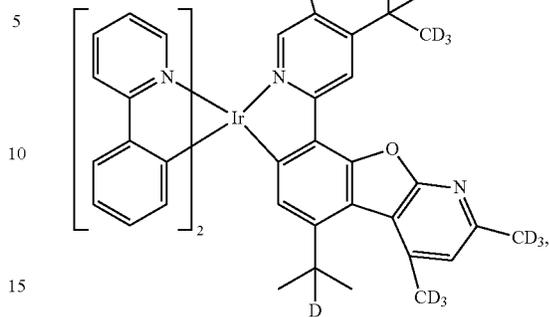


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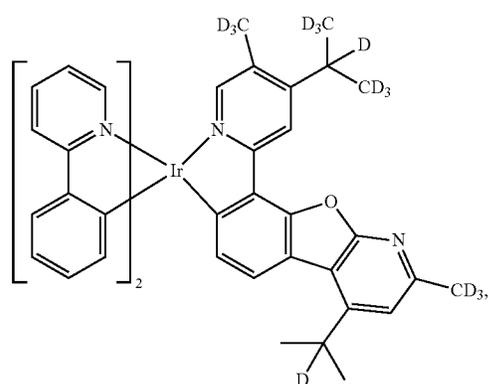
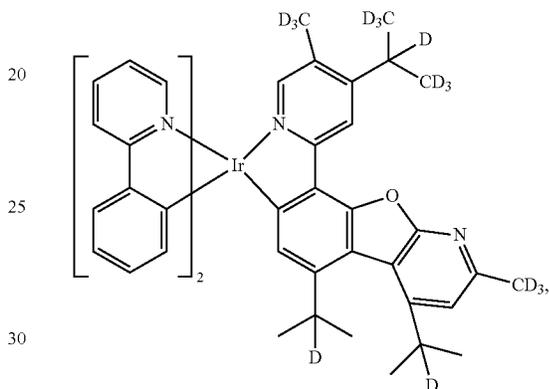
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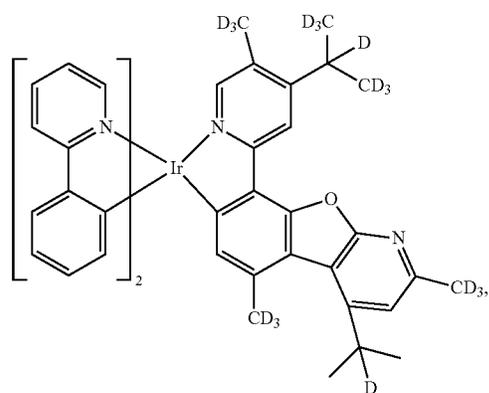
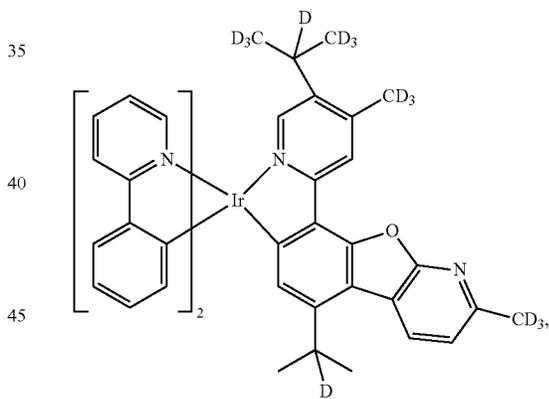
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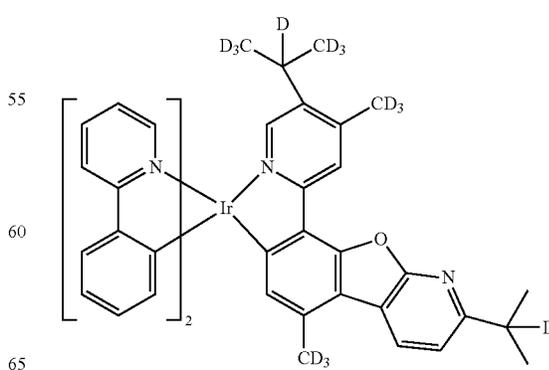
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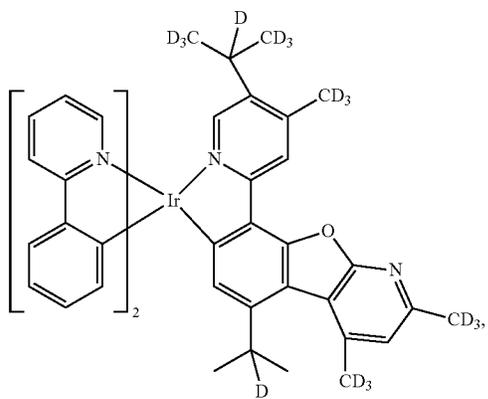
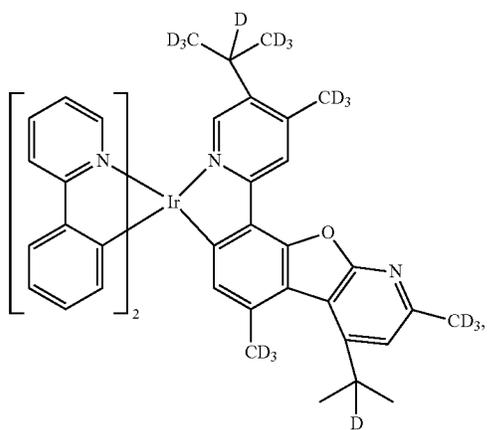
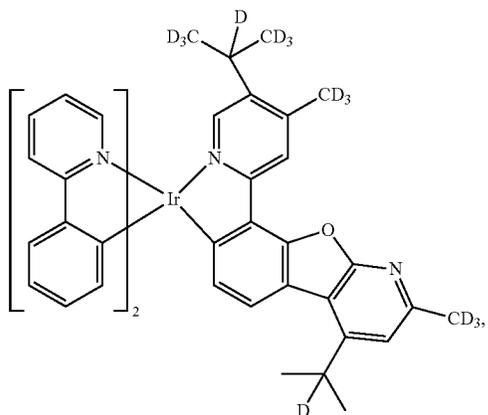
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D79



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**272**

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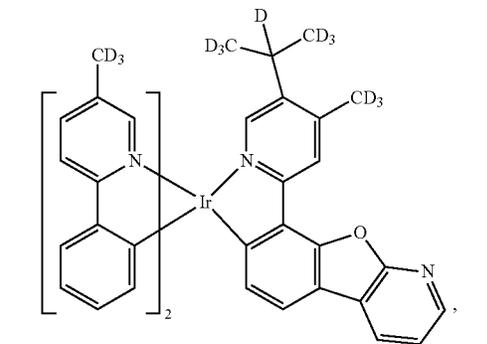
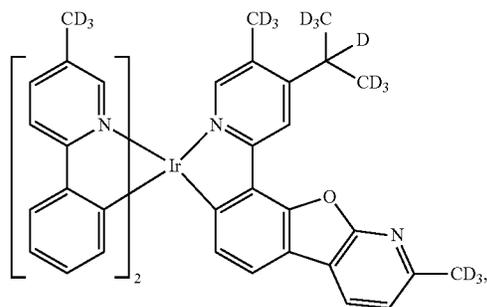
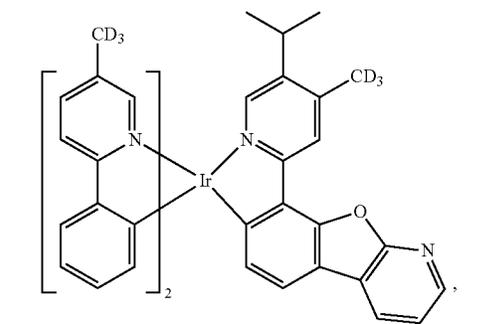
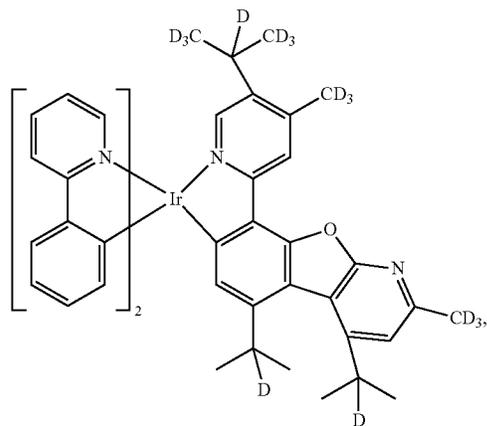
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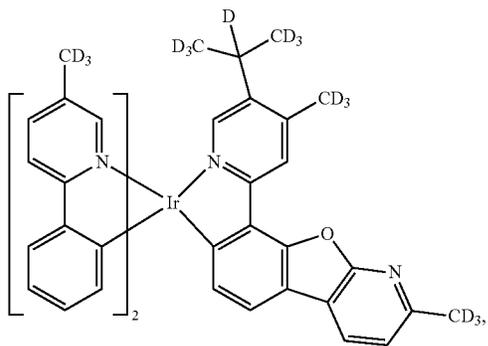
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**274**

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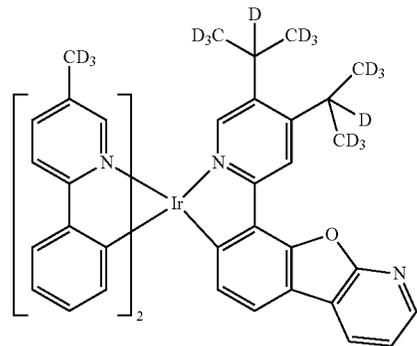
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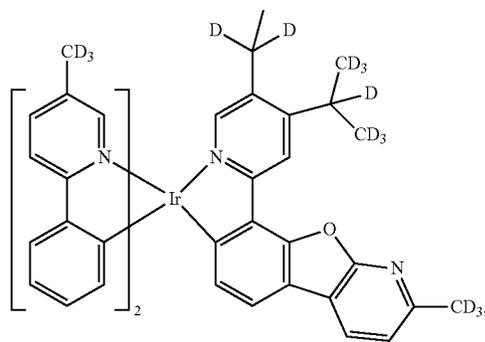
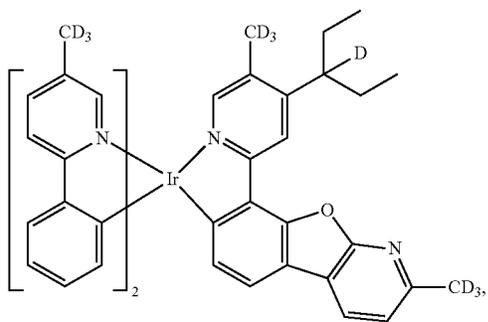
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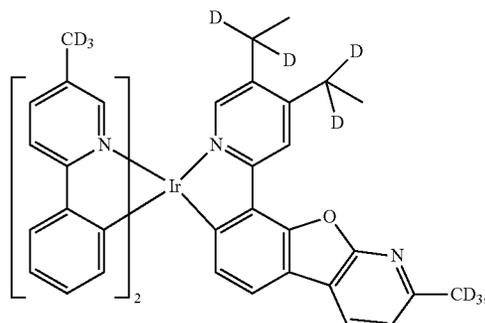
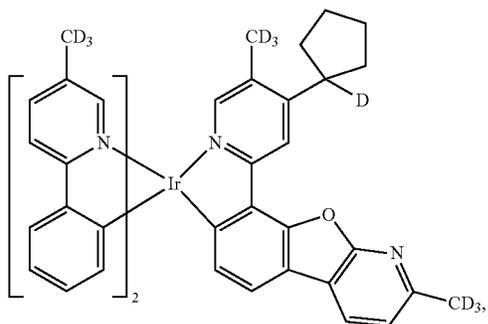
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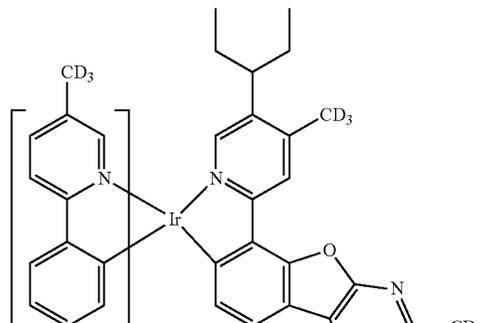
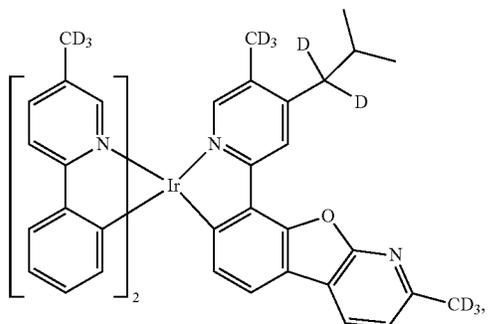
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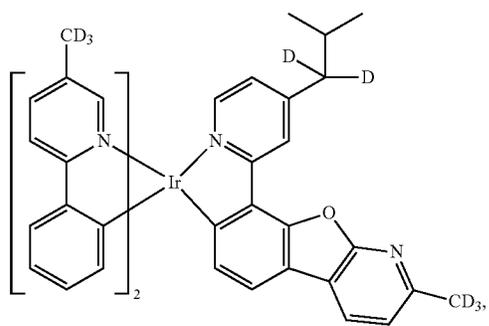
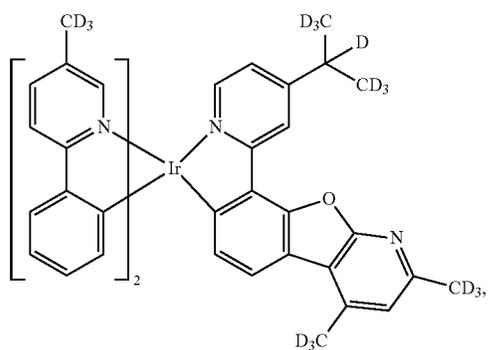
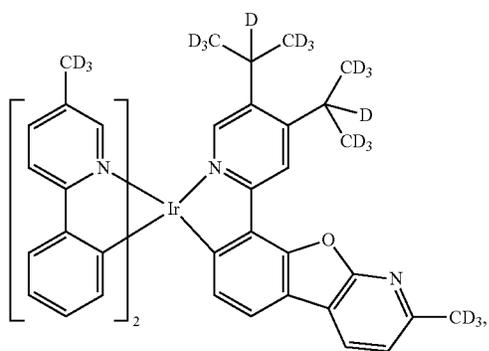
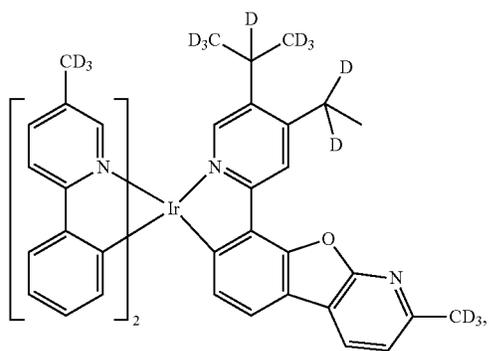
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**276**

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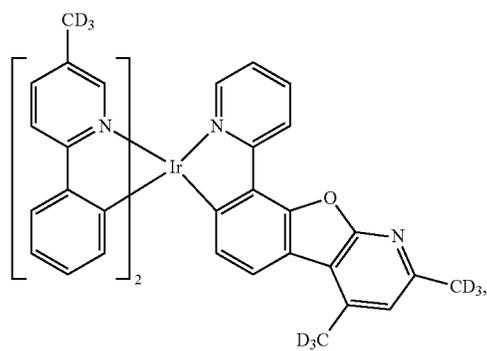
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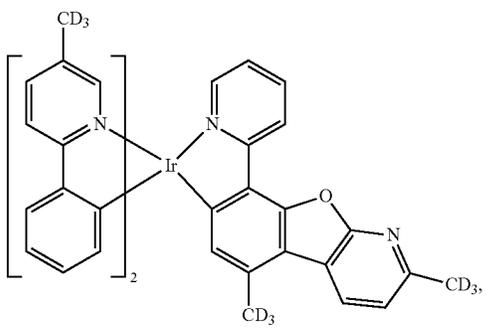
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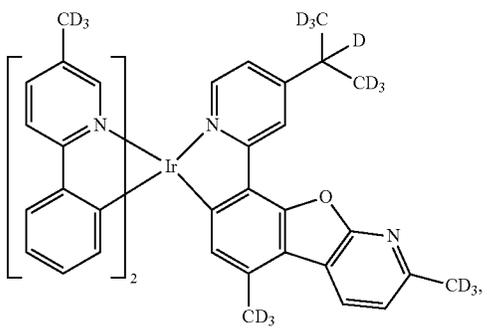
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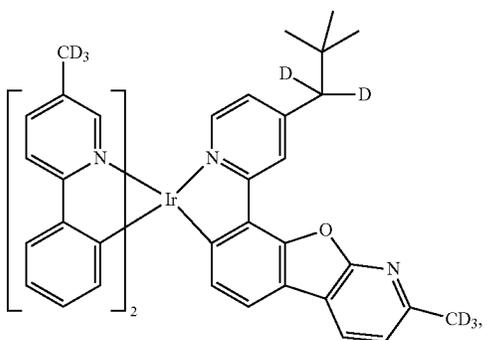
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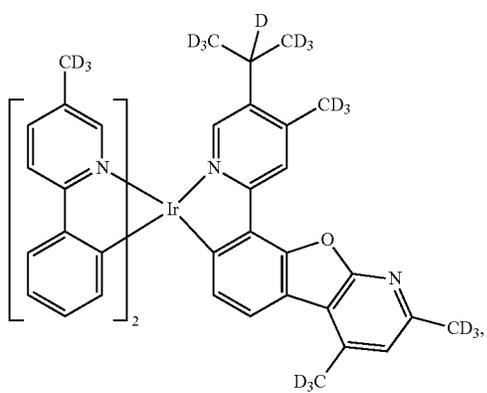
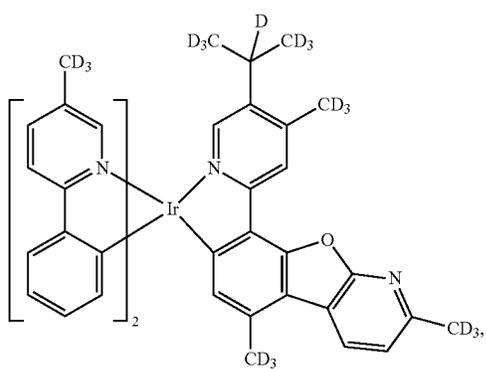
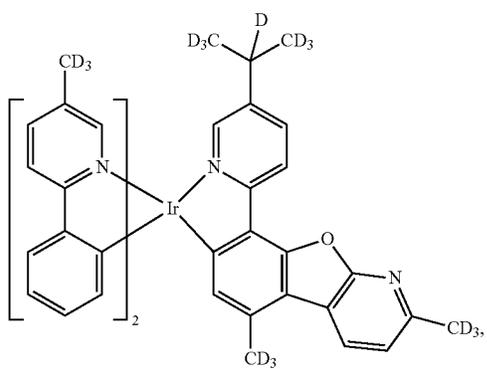
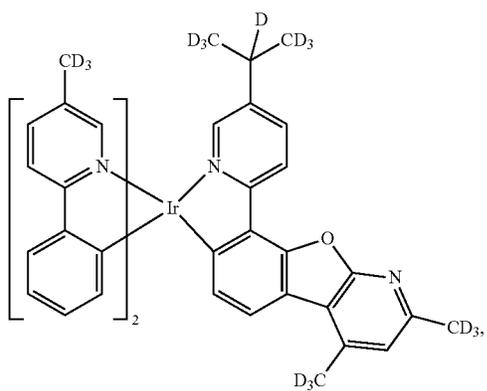
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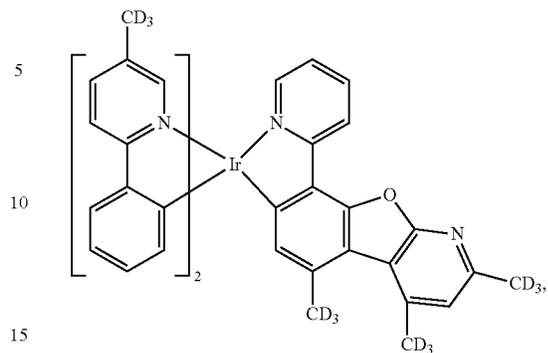


278

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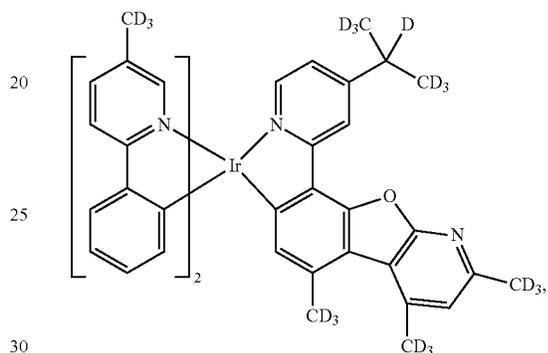
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D107



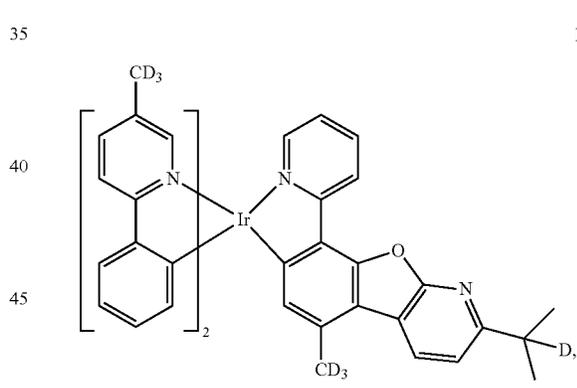
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D108



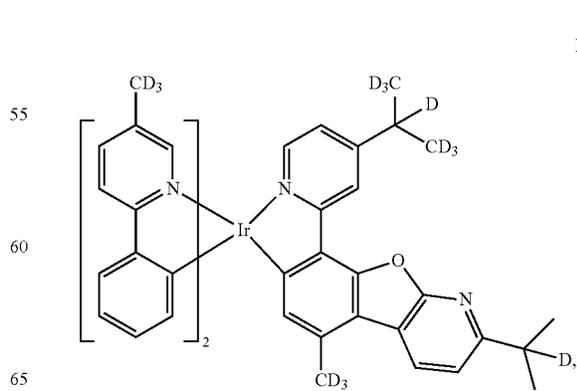
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D109

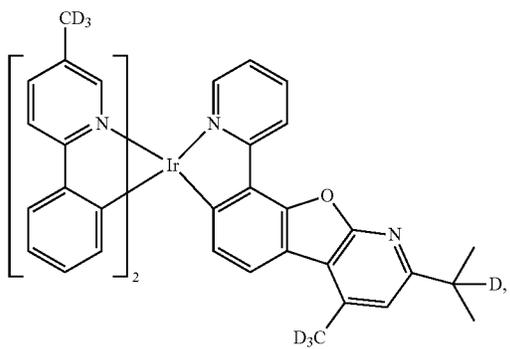


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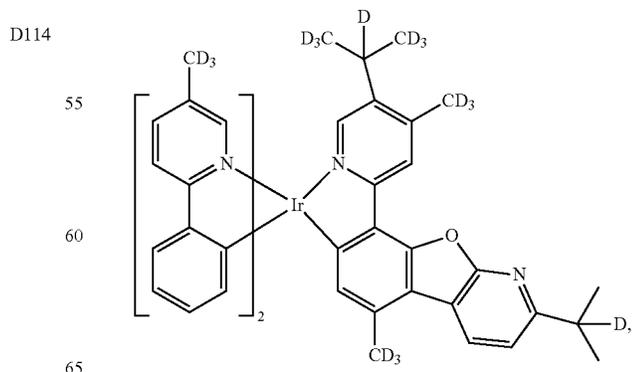
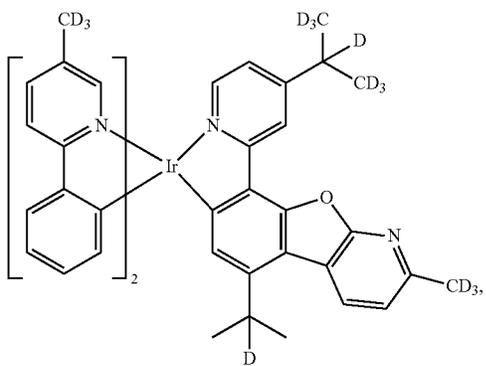
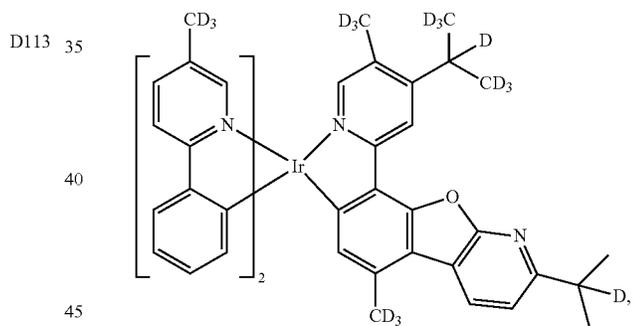
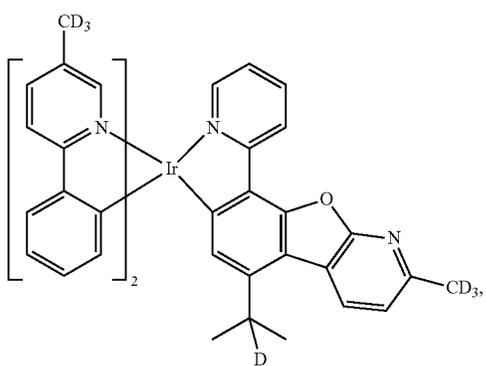
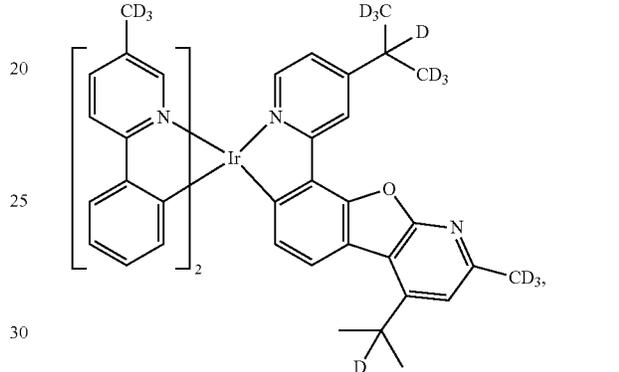
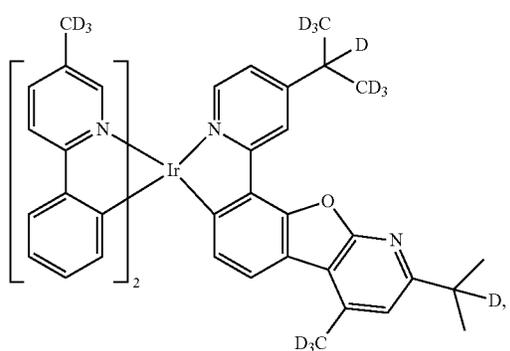
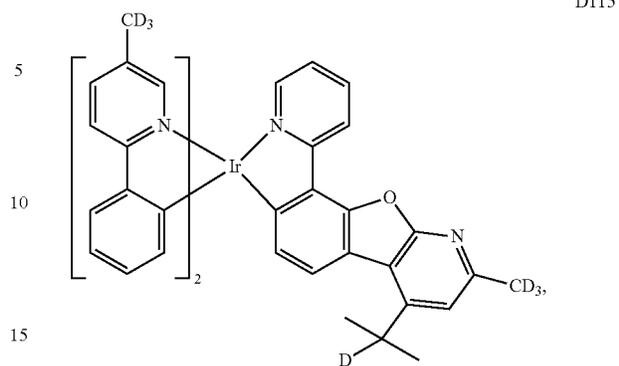
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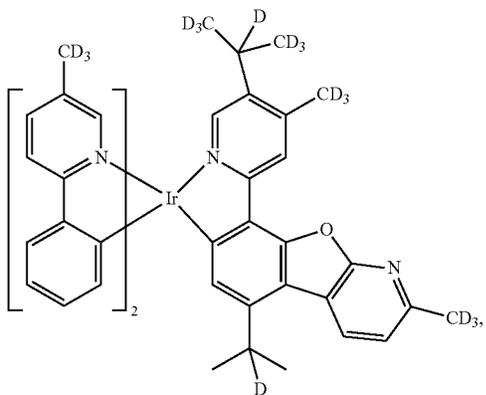
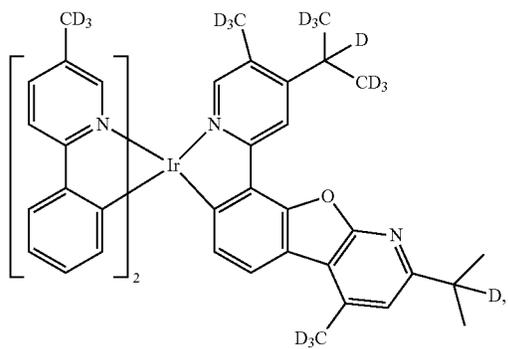
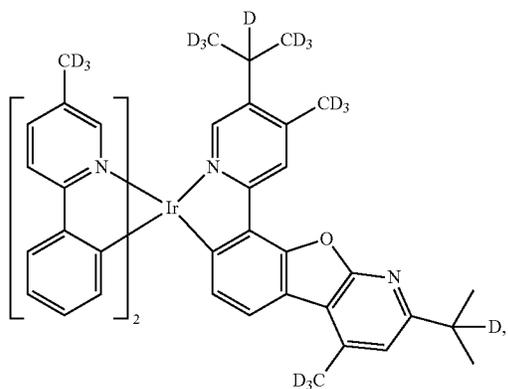
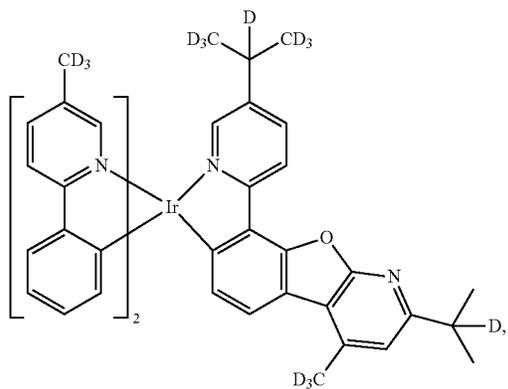


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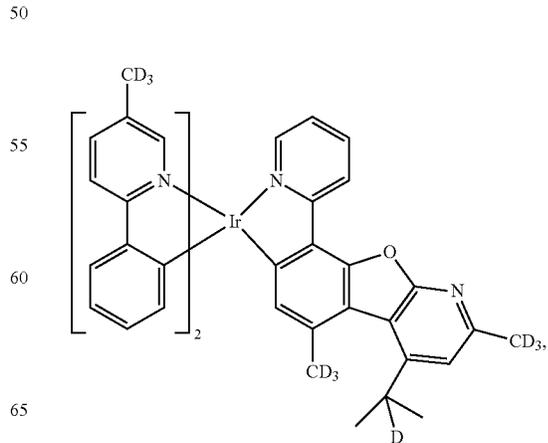
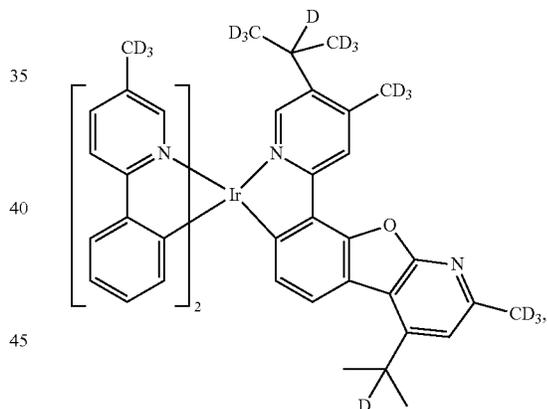
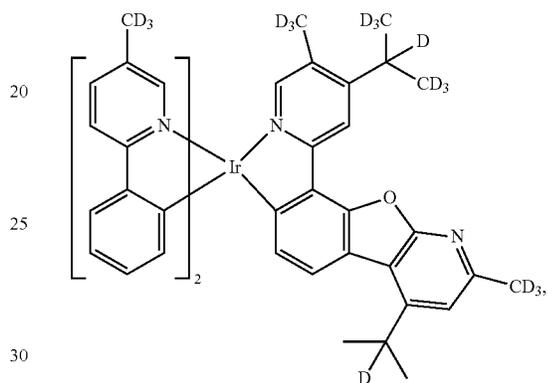
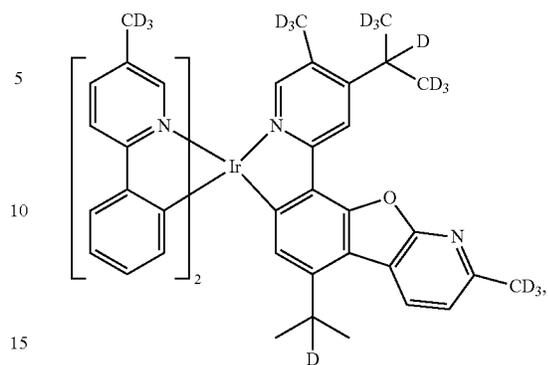
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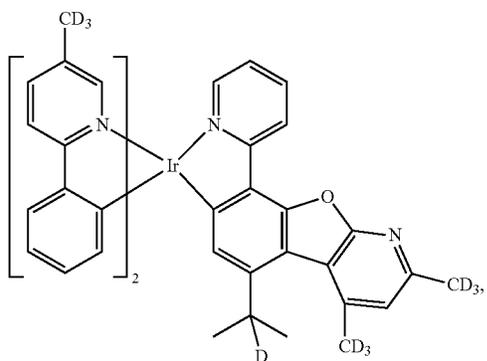
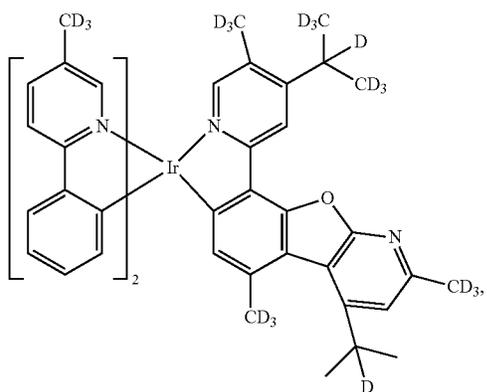
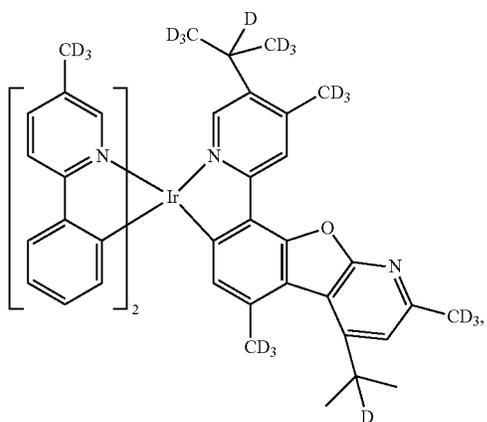
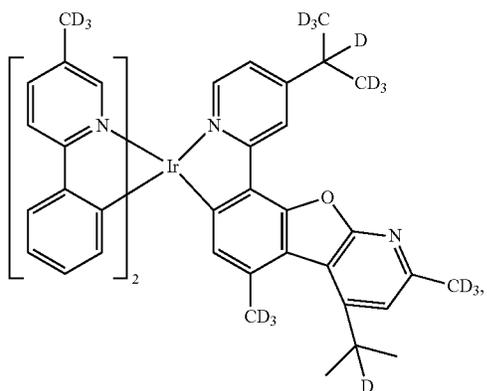
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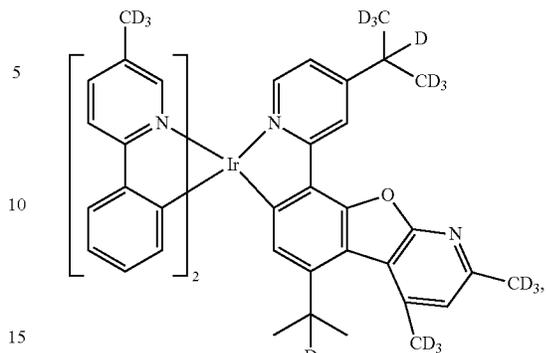
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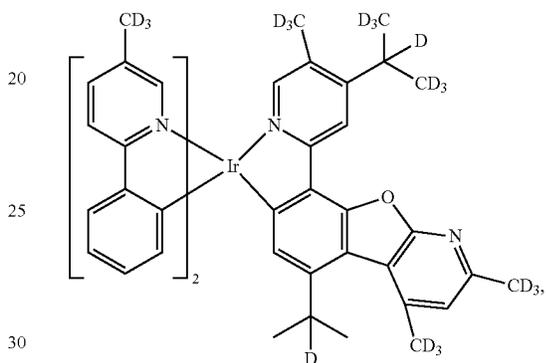
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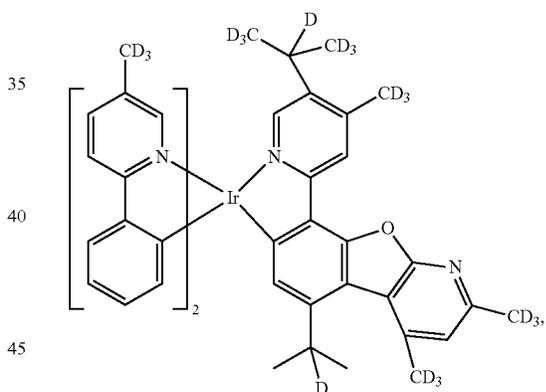
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D128



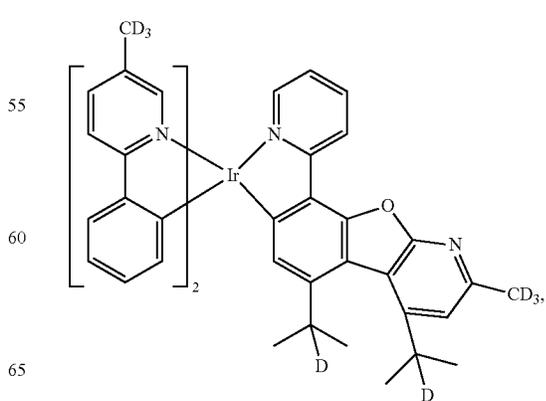
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D129



D133

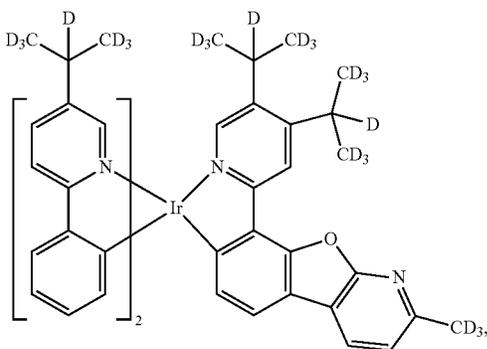
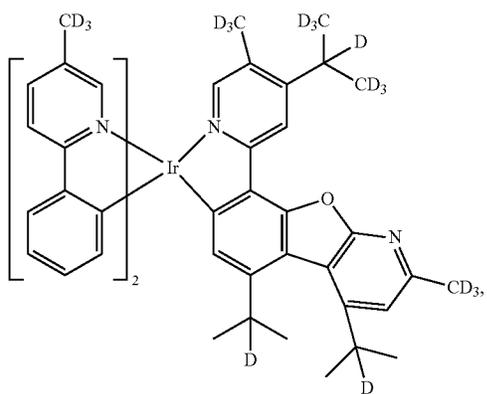
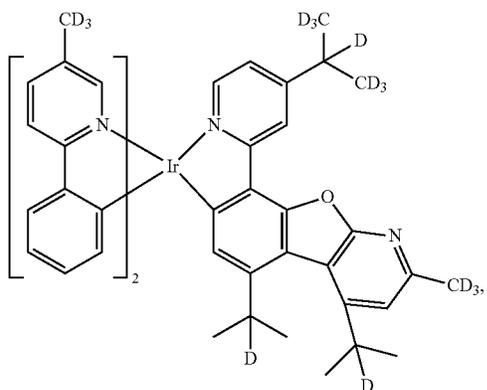
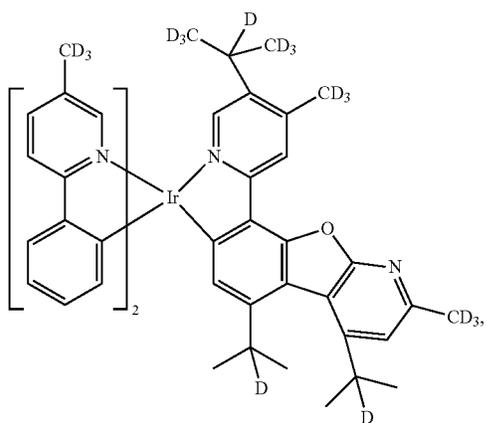
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D134

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**286**

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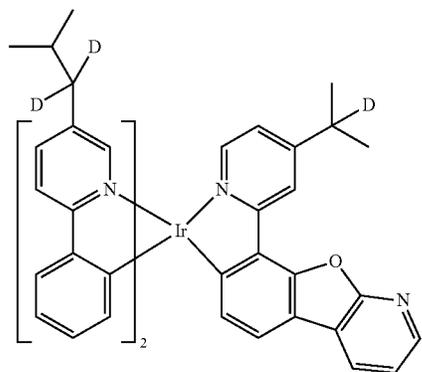
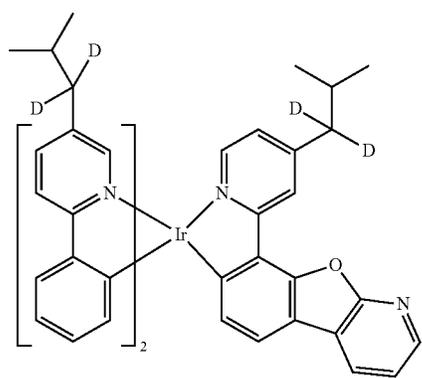
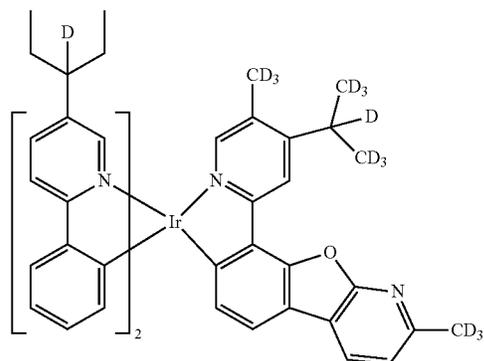
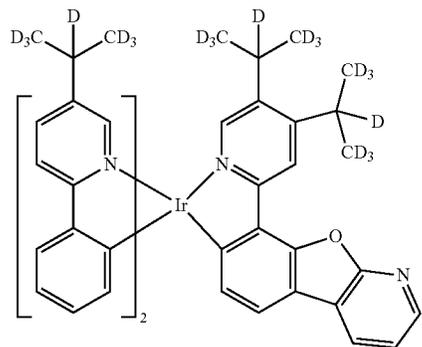
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D139

D140

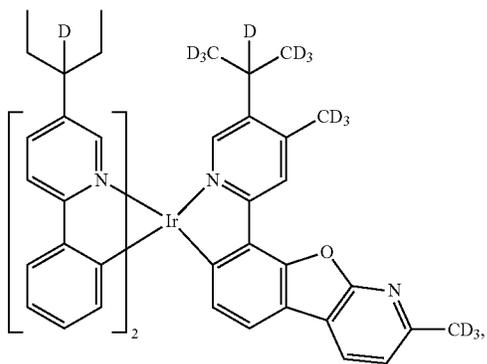
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**287**

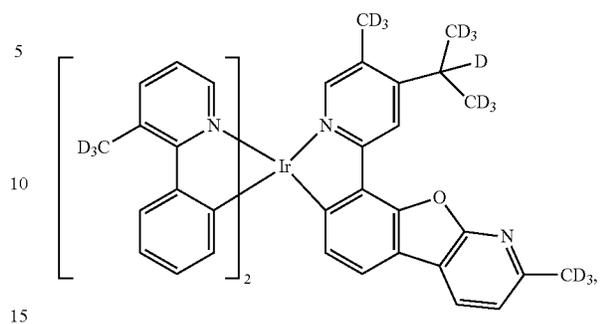
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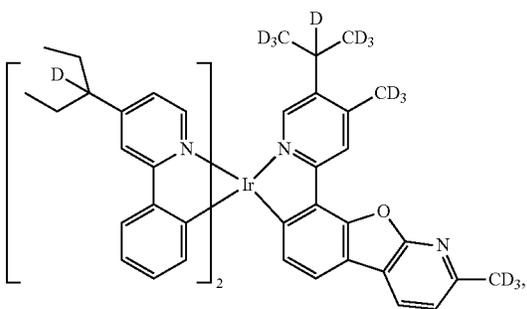
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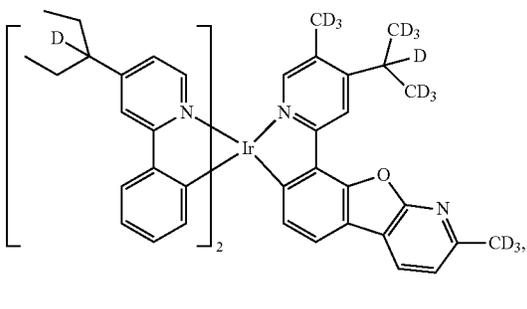
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D144 20



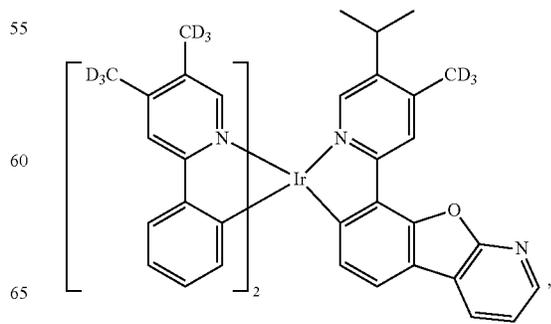
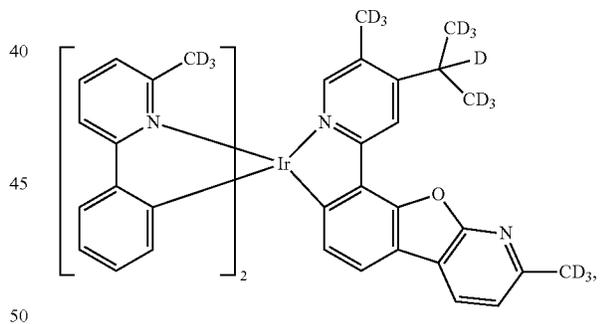
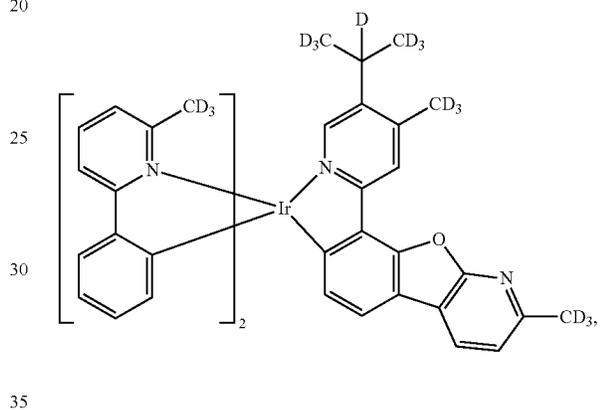
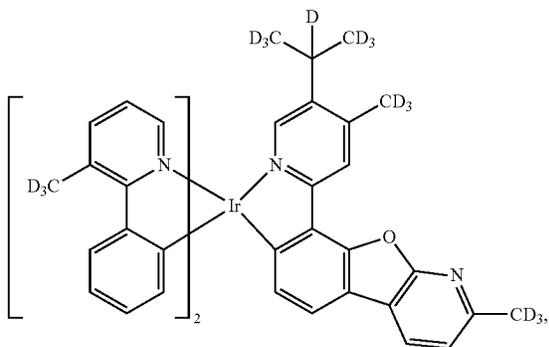
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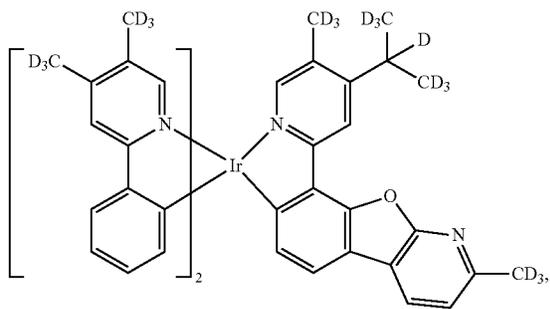
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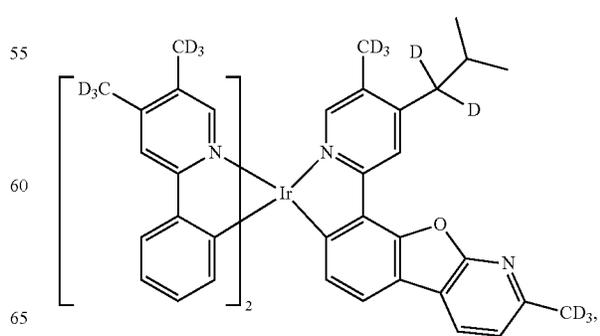
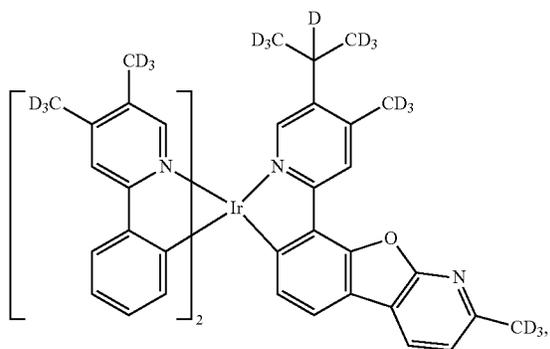
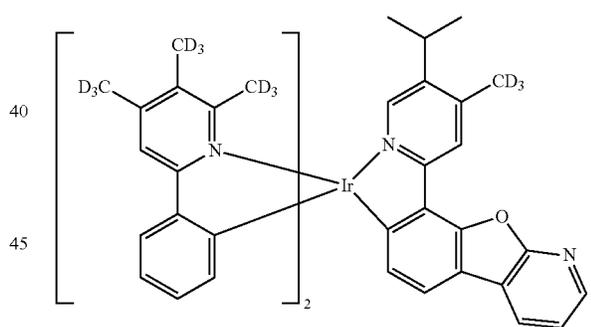
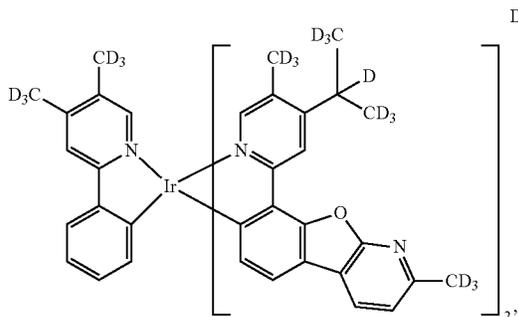
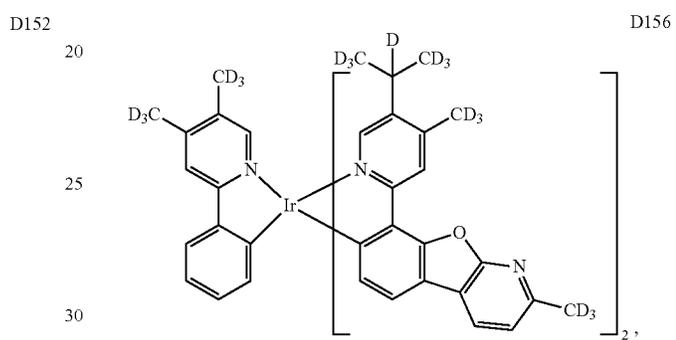
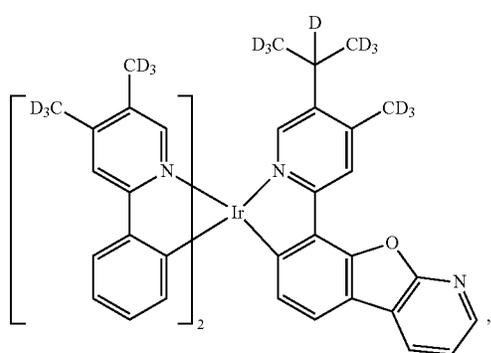
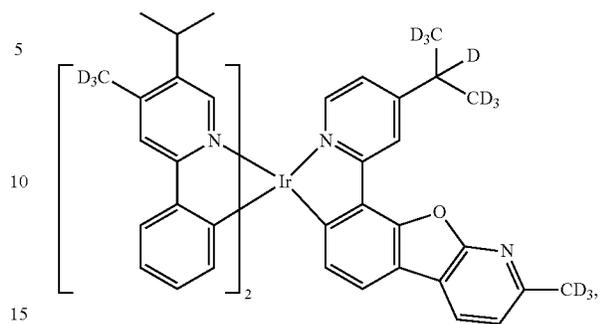


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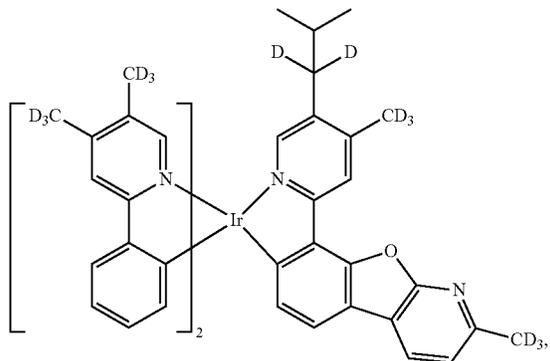
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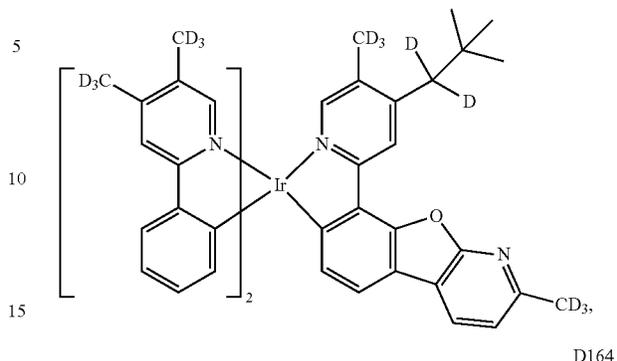
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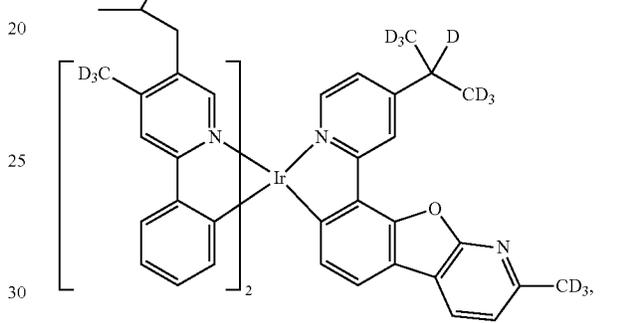
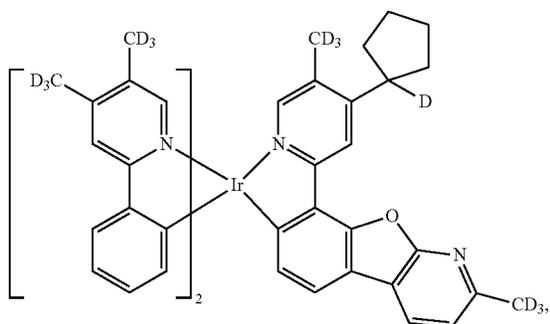
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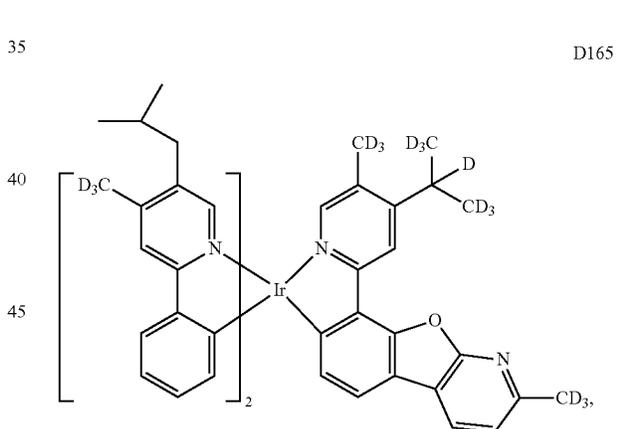
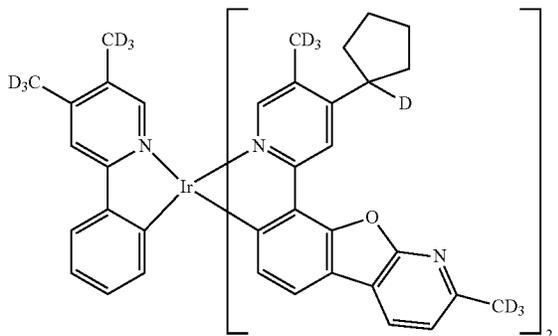
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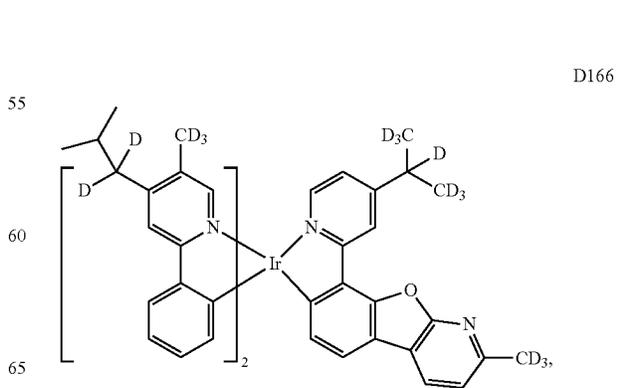
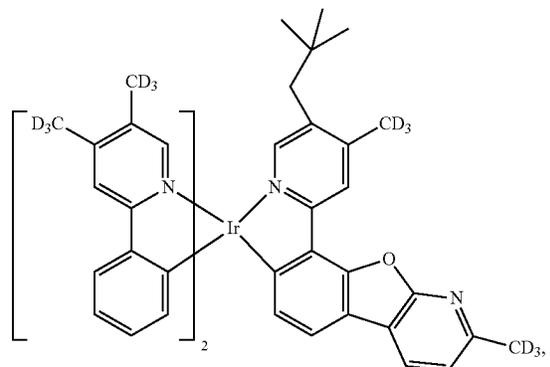
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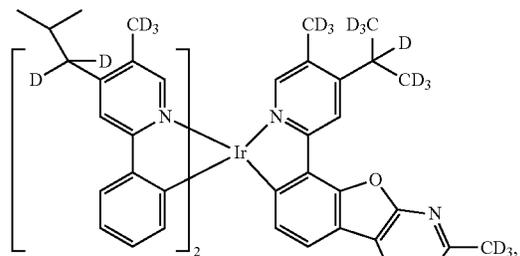


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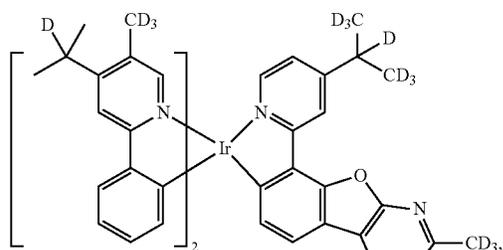
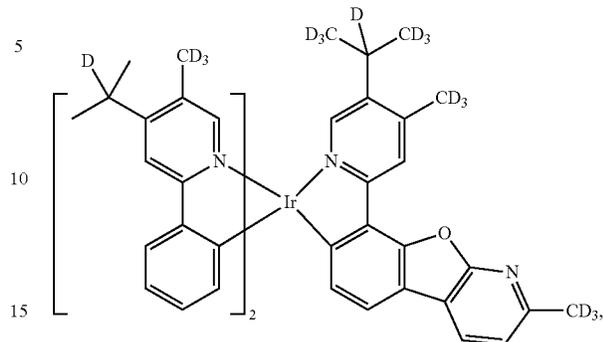
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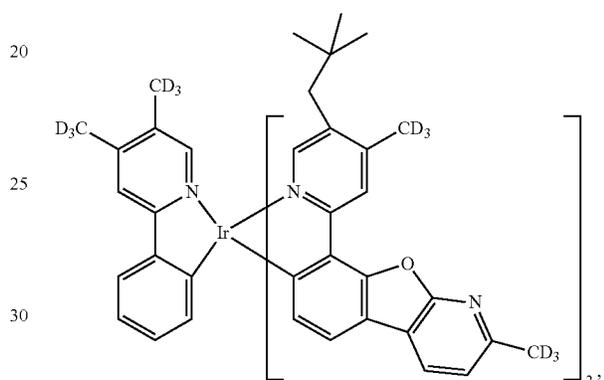


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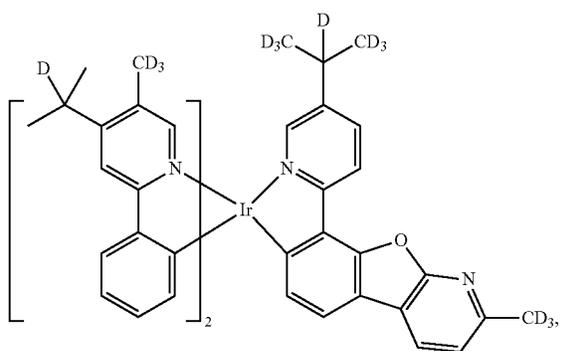
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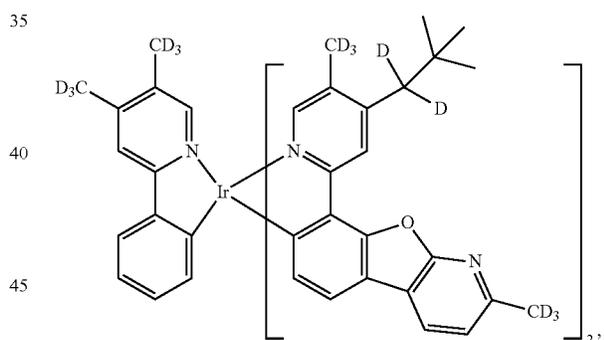
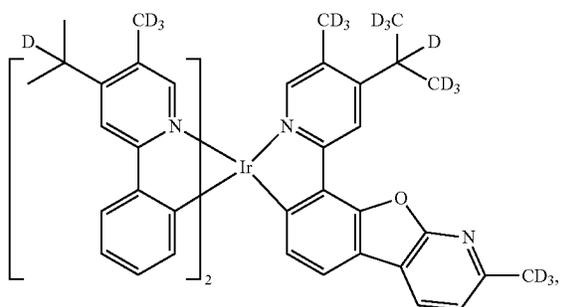
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D169



D170



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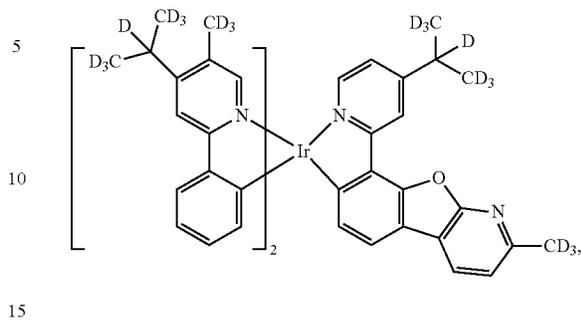
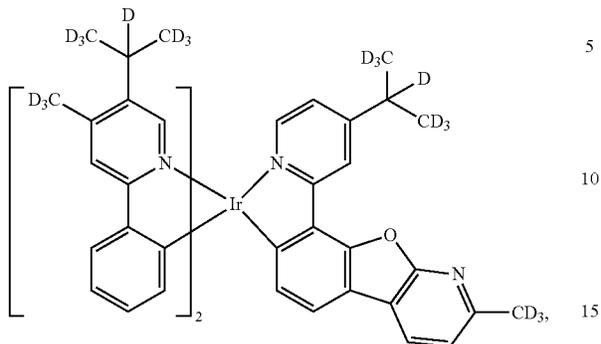
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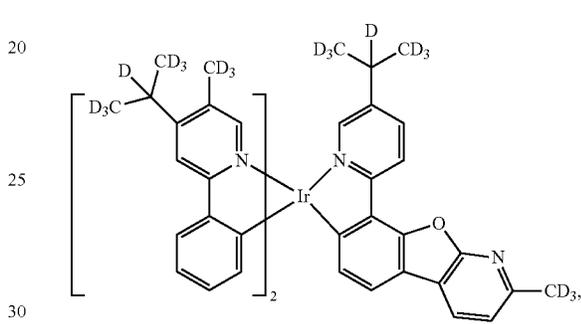
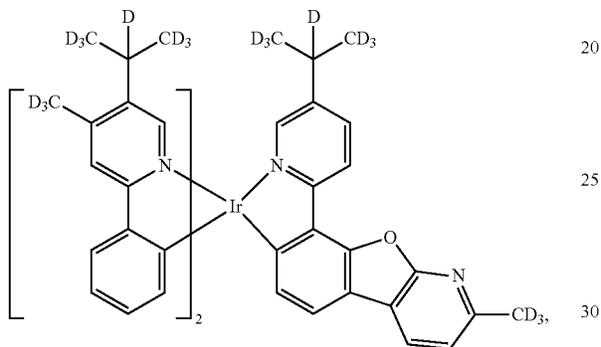
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D179



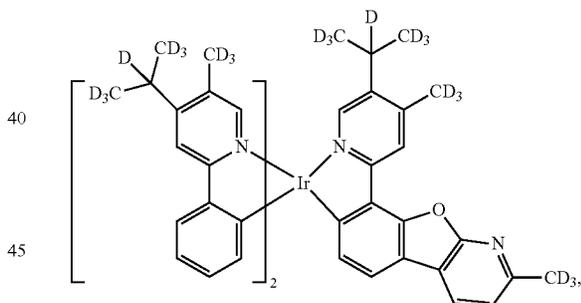
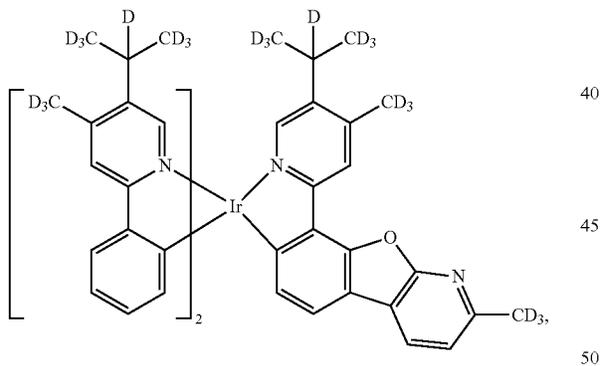
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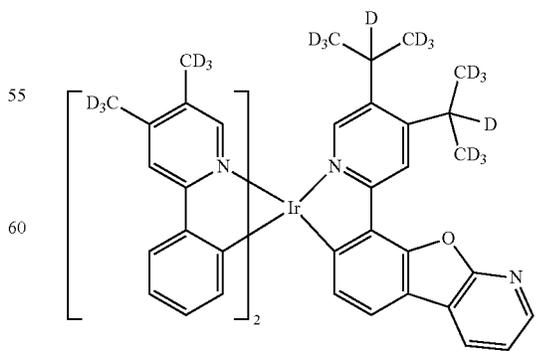
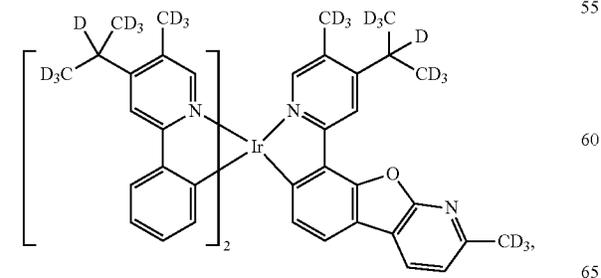
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D181



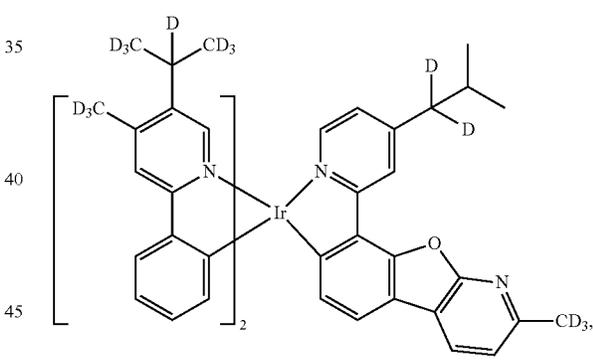
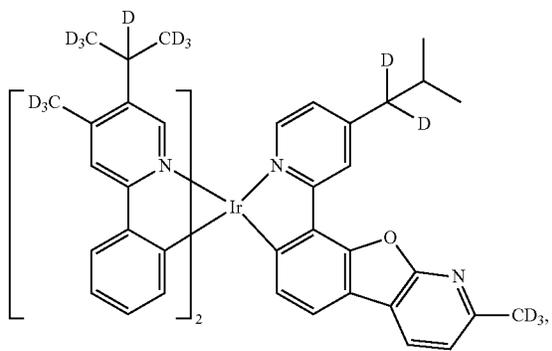
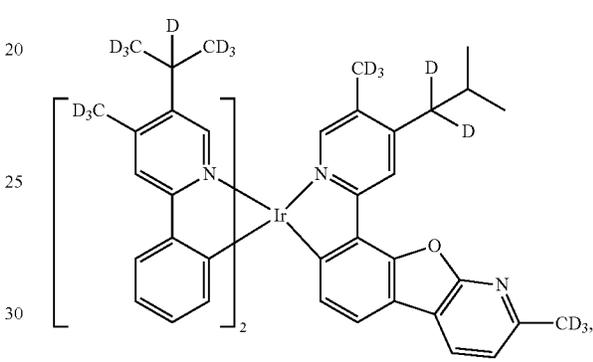
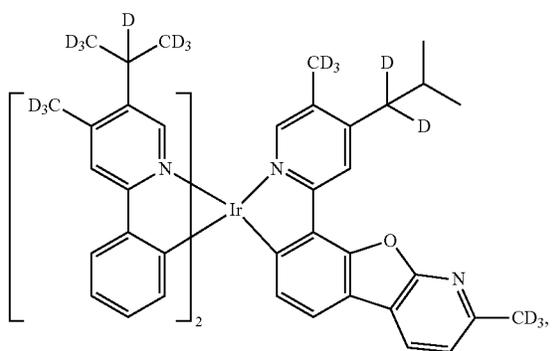
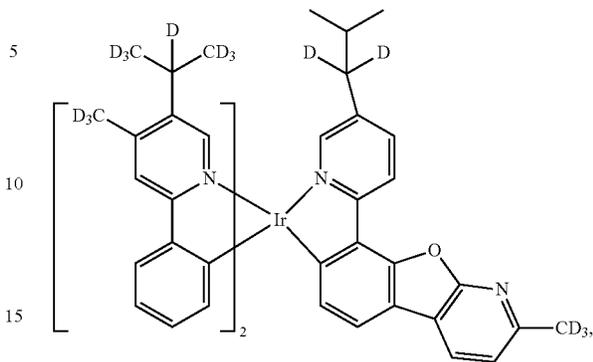
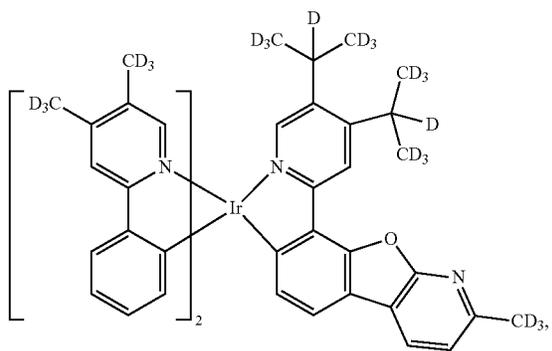
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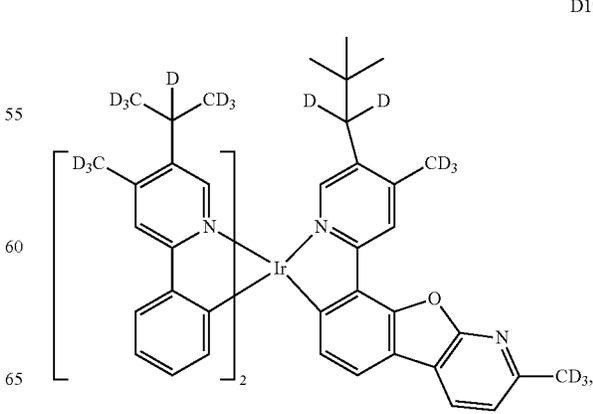
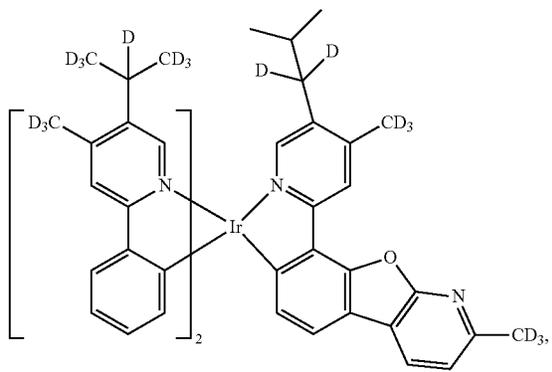


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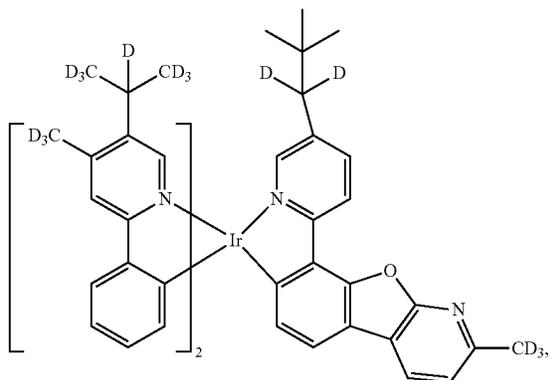
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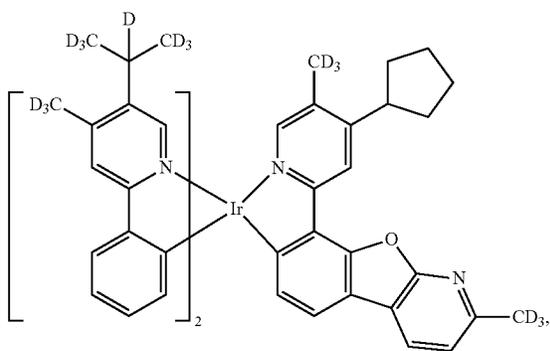
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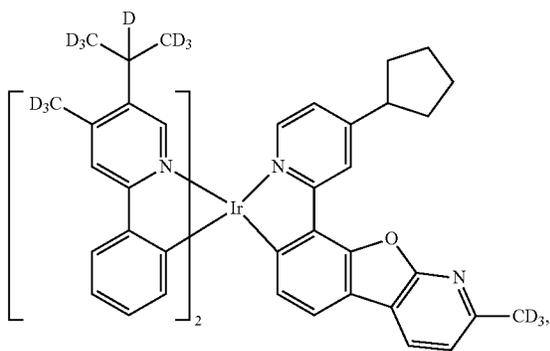
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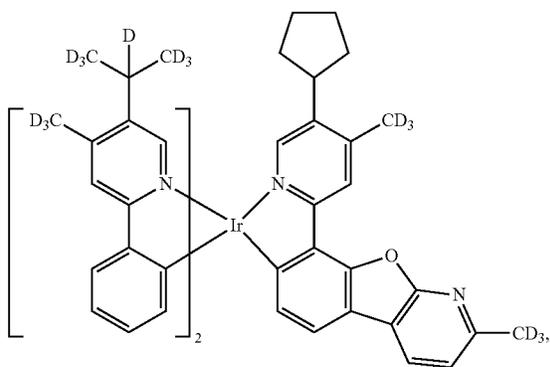
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D193



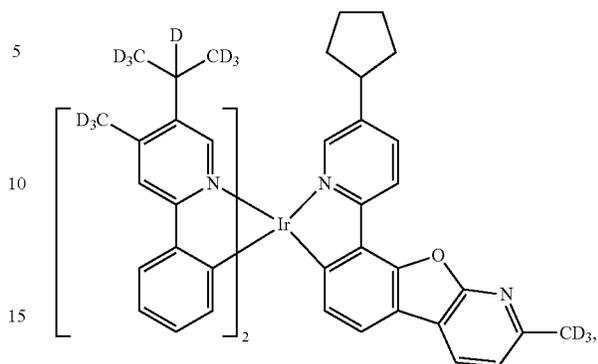
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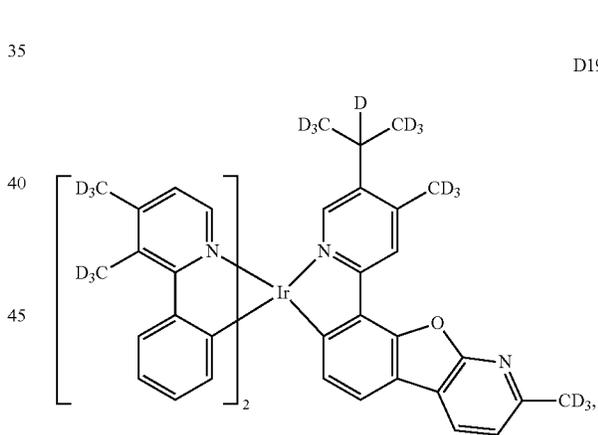
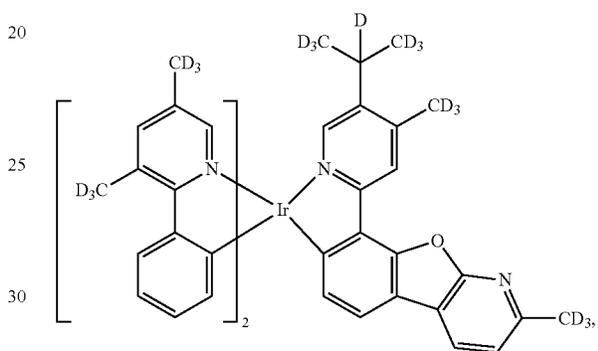
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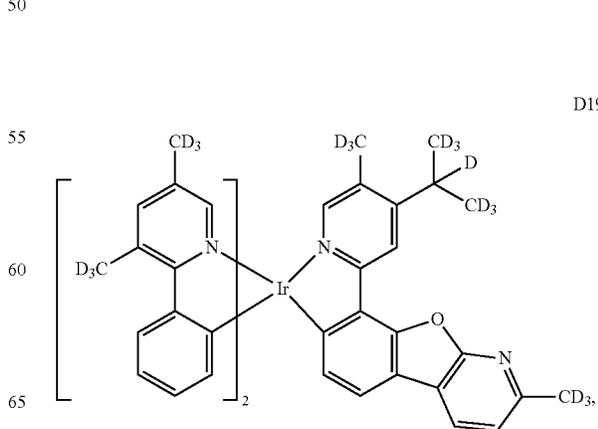
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D196



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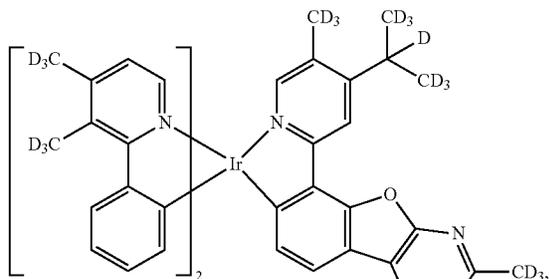


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D199



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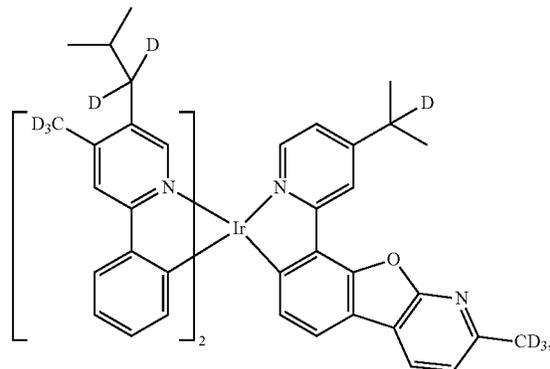
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D203



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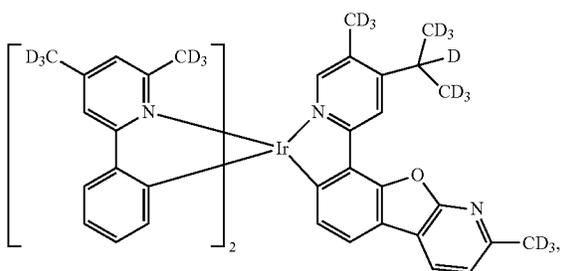
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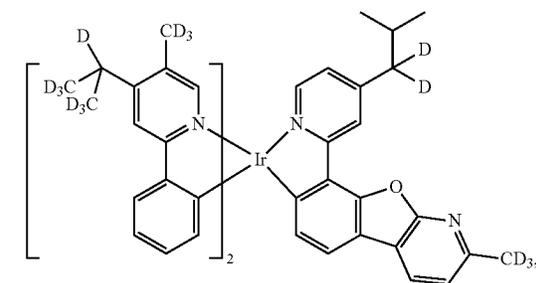
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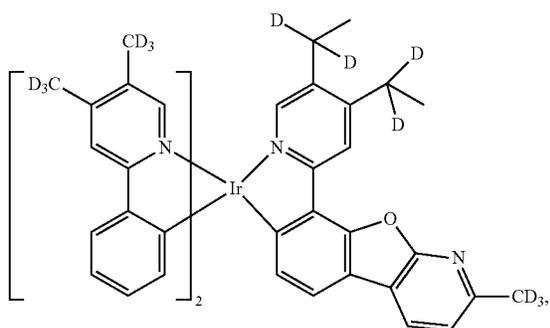
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D205

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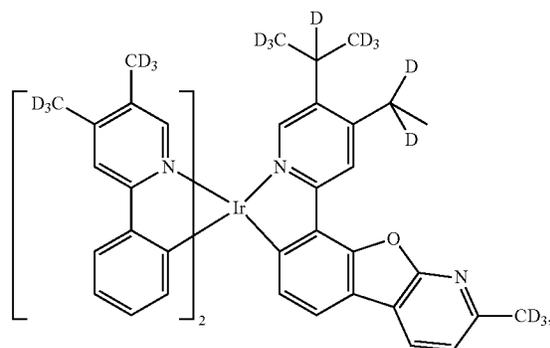
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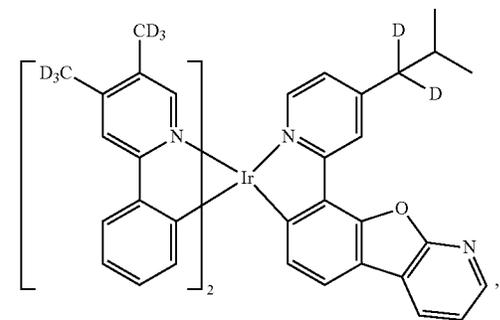
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D206

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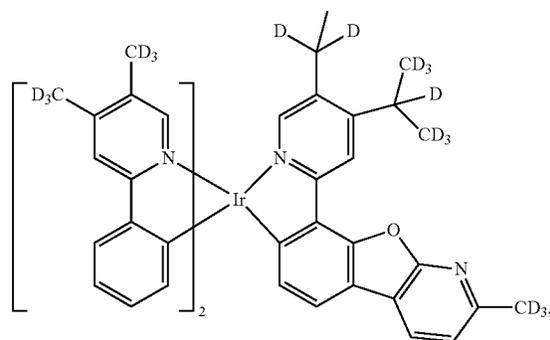
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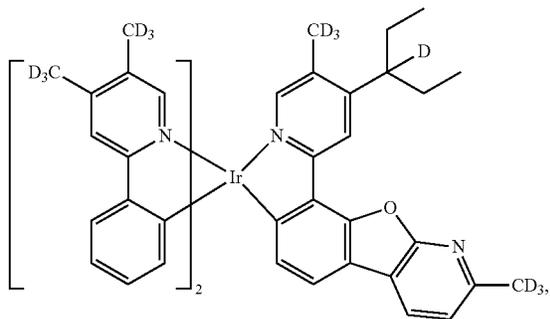
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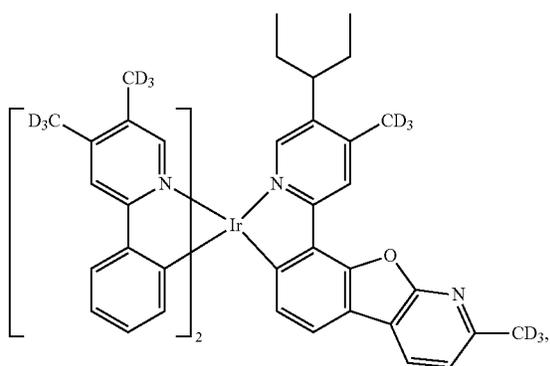
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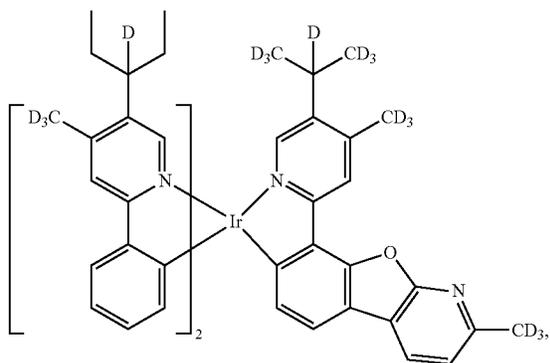
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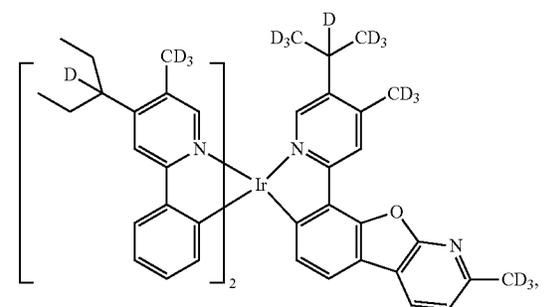
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D209



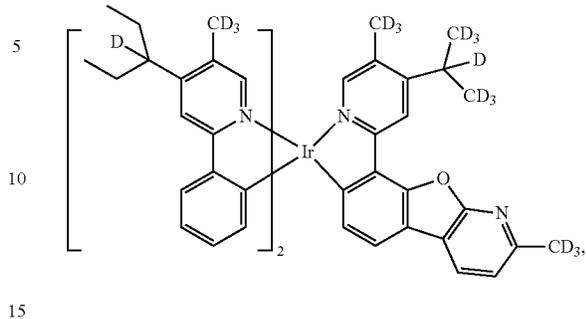
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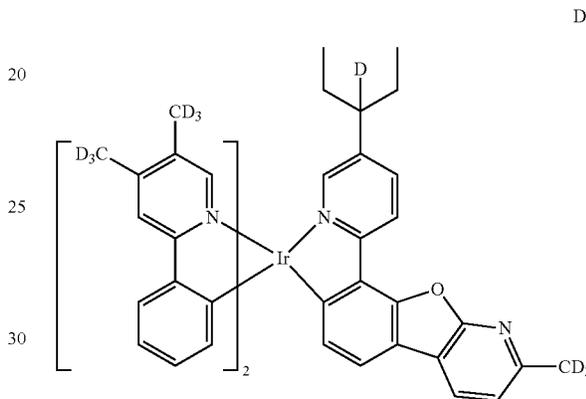
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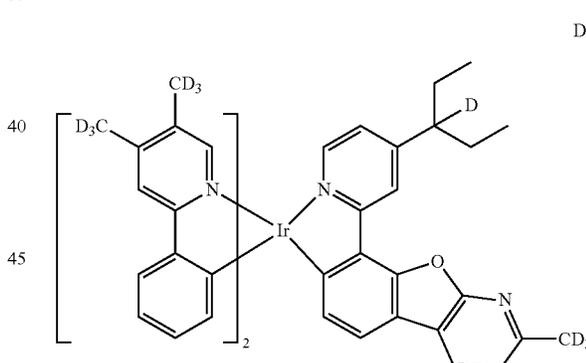
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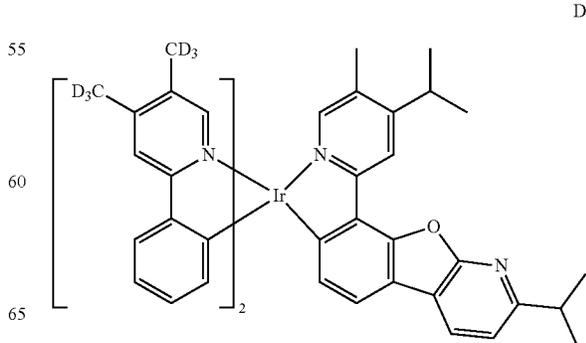
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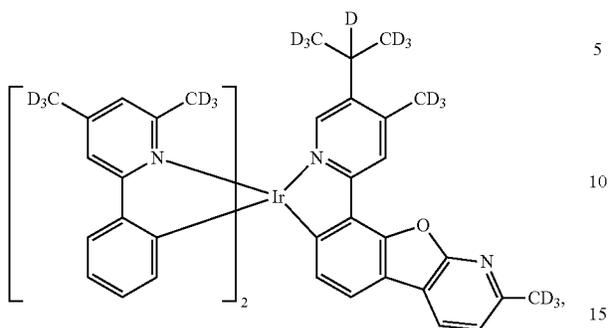
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**305**

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D215



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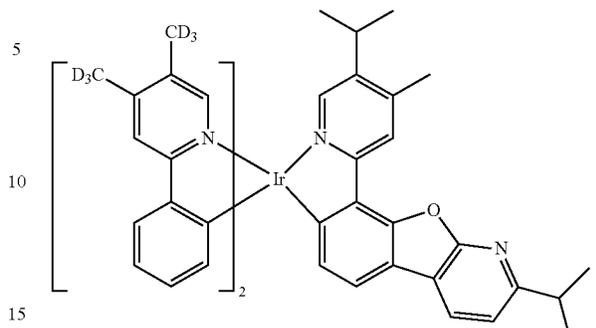
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D219



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D220

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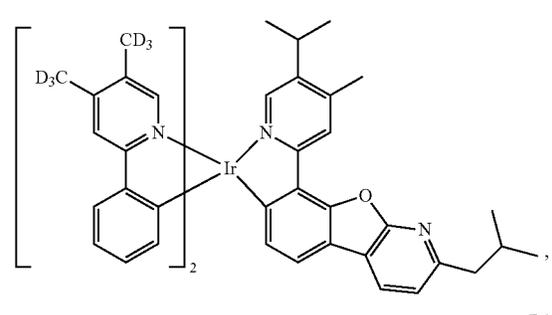
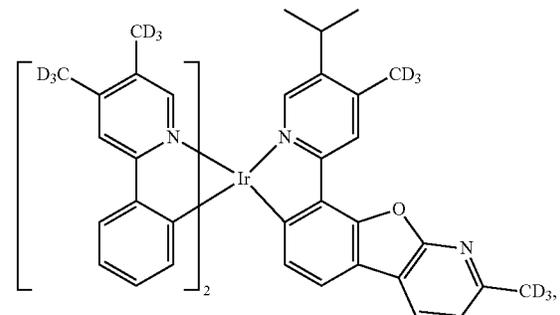
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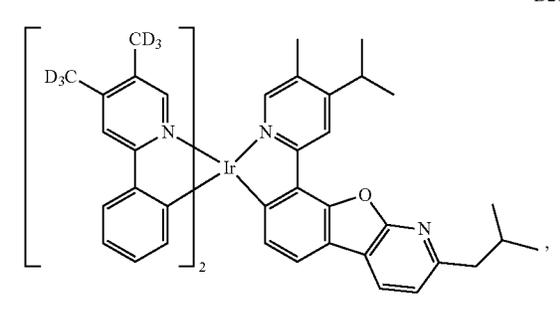
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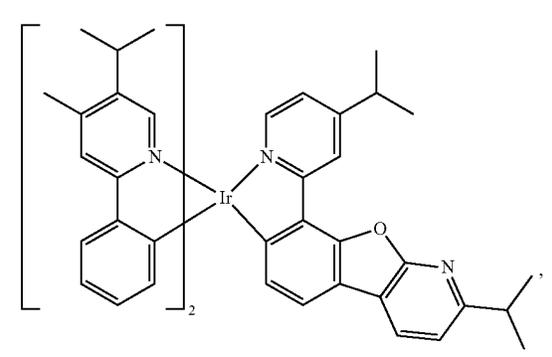
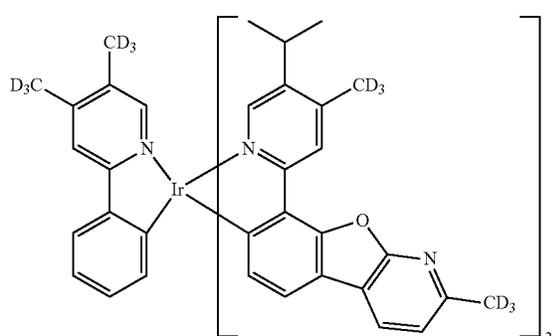


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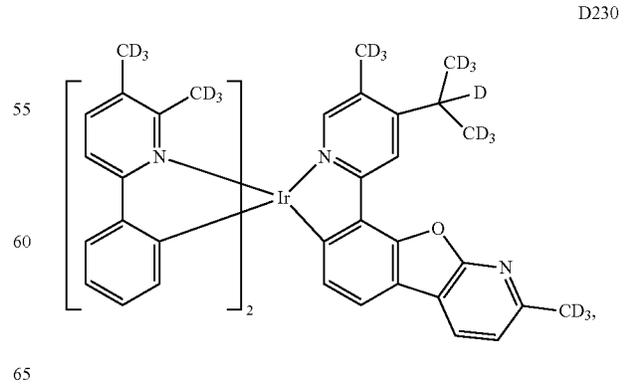
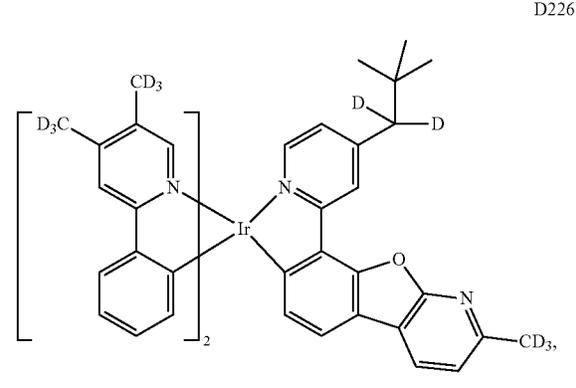
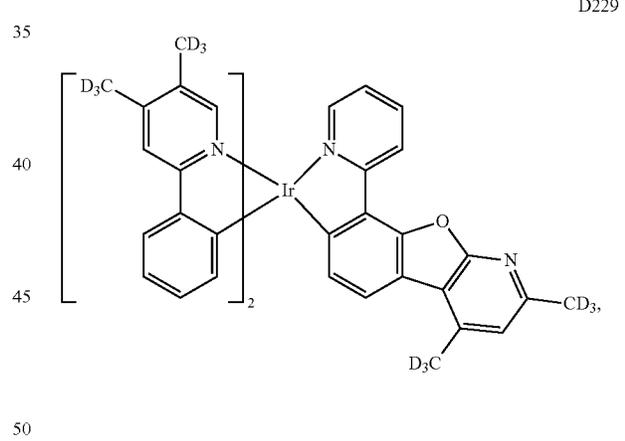
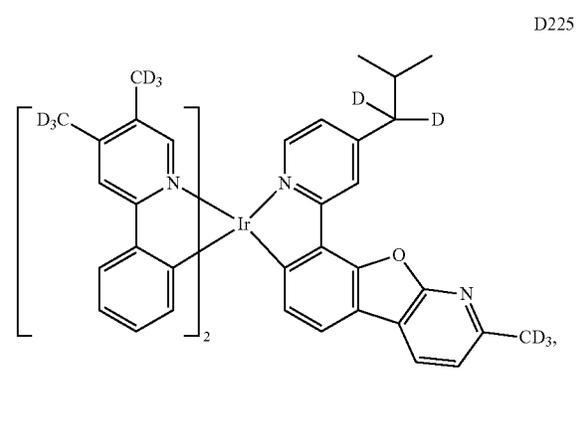
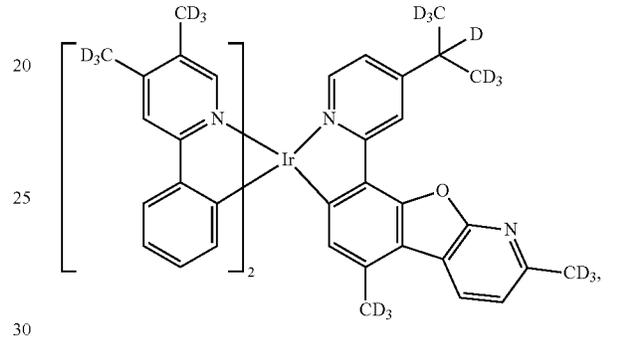
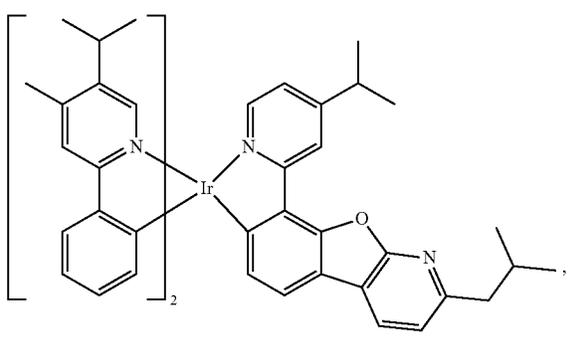
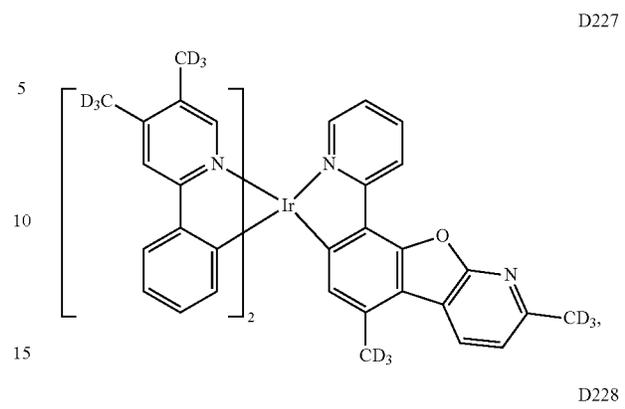
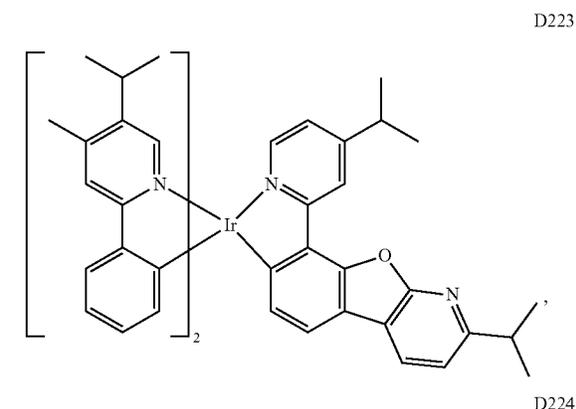
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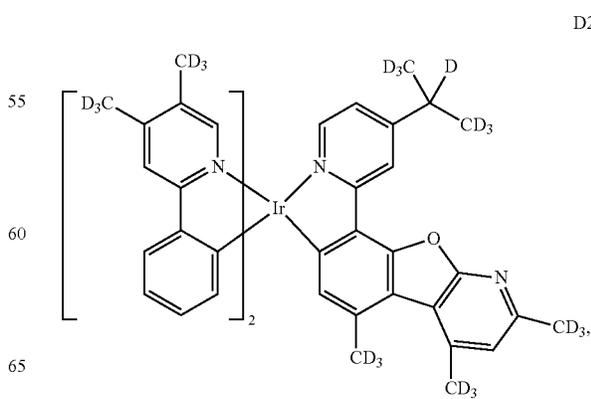
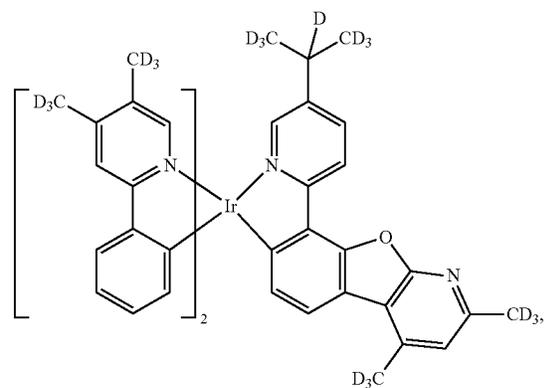
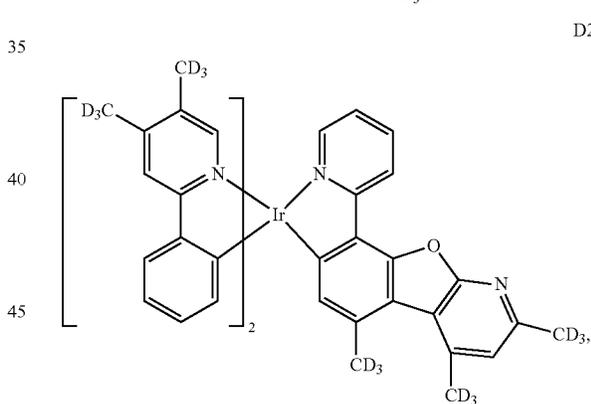
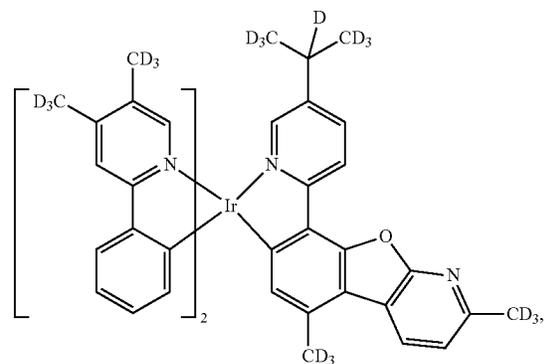
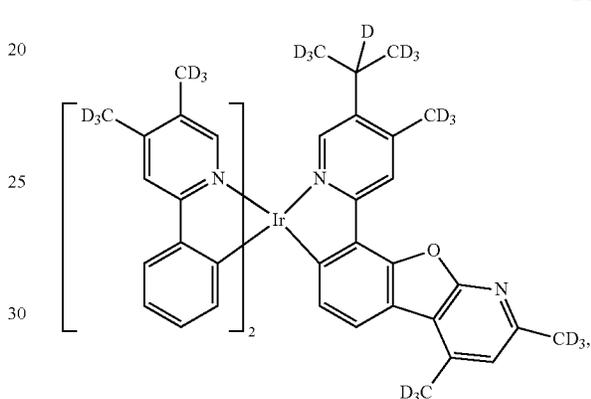
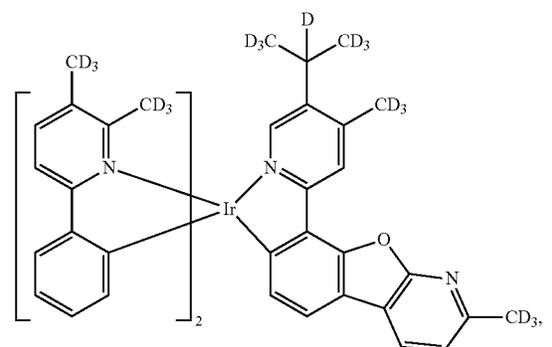
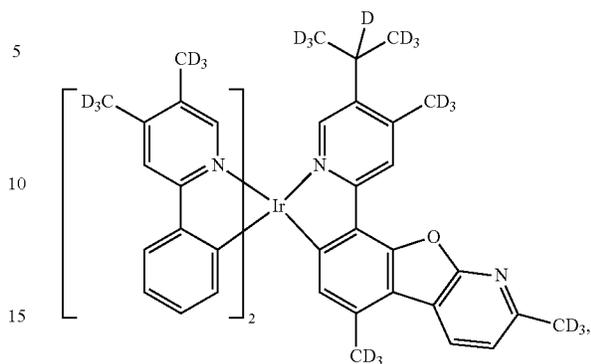
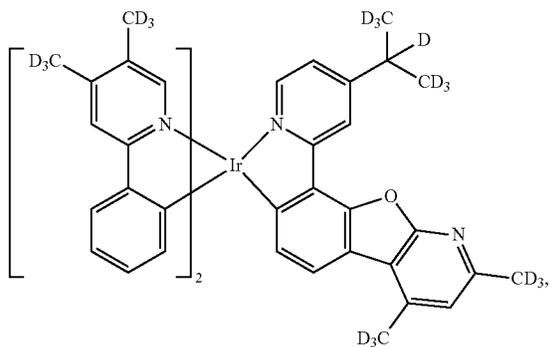
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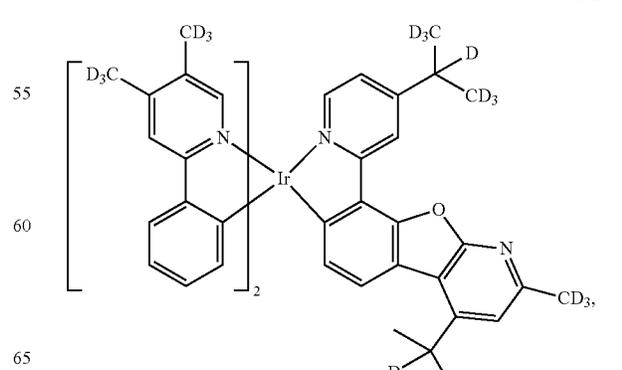
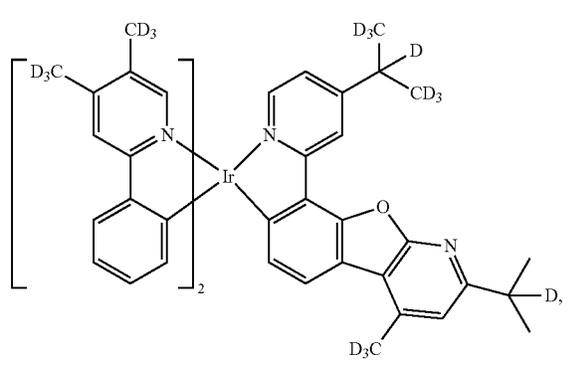
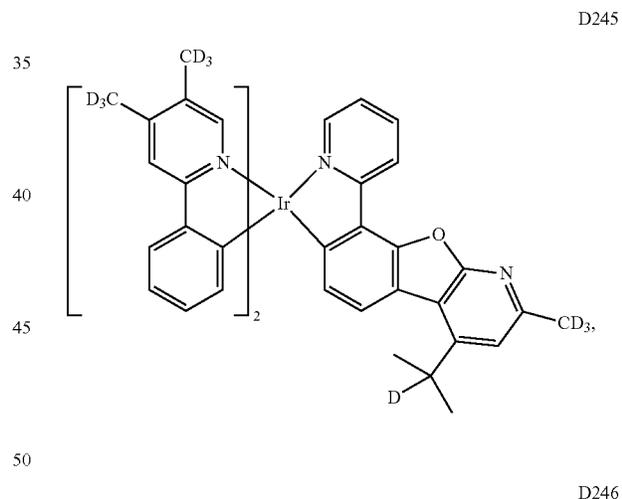
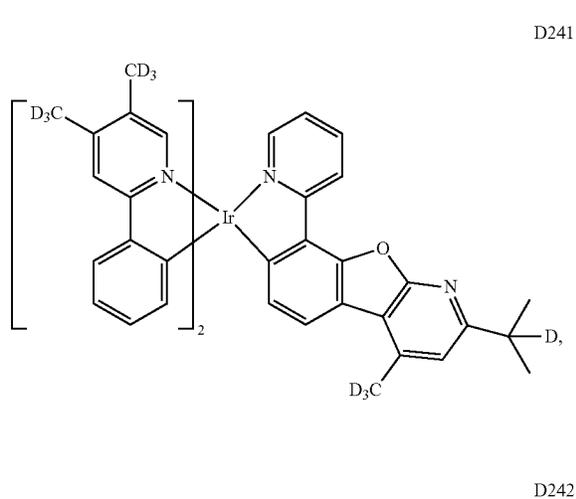
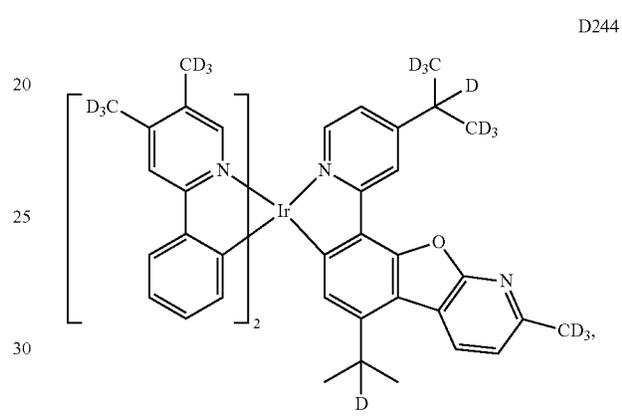
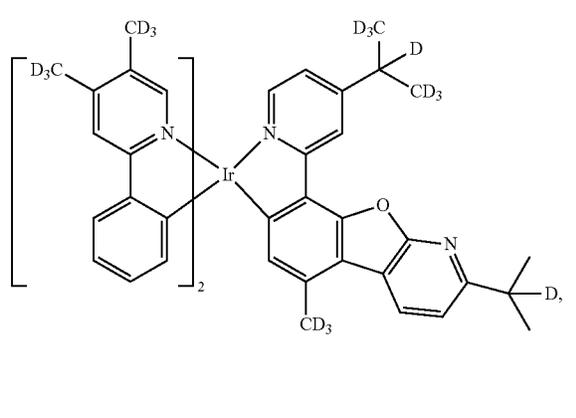
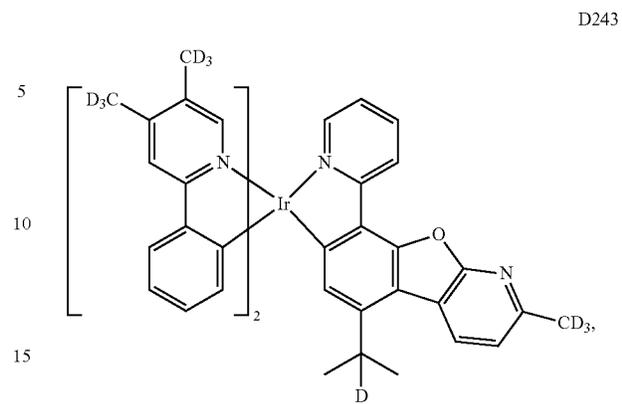
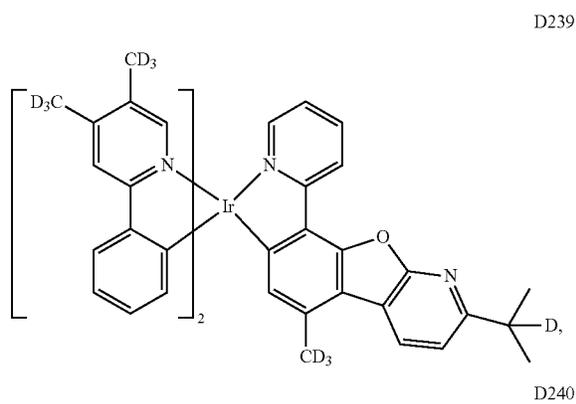
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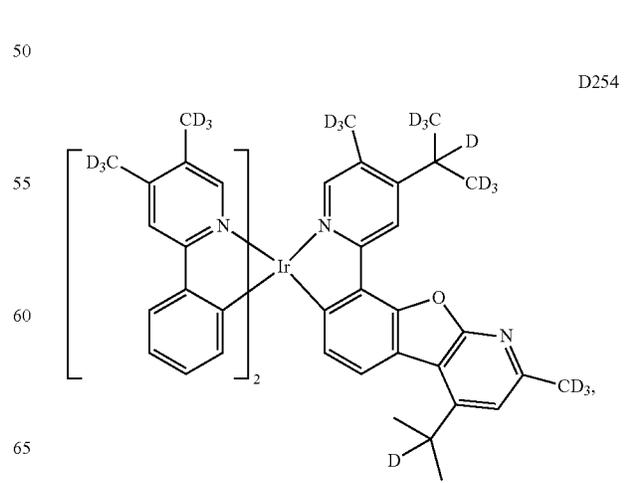
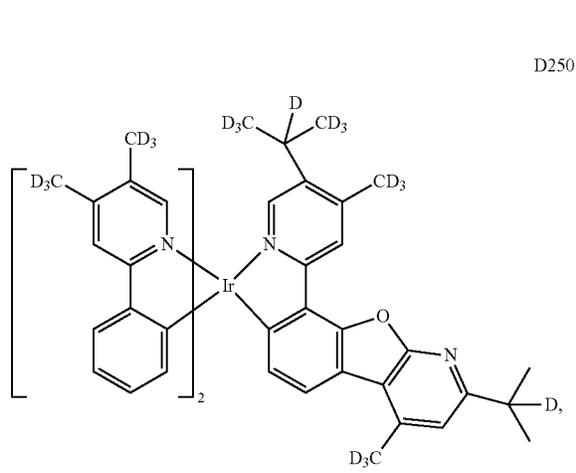
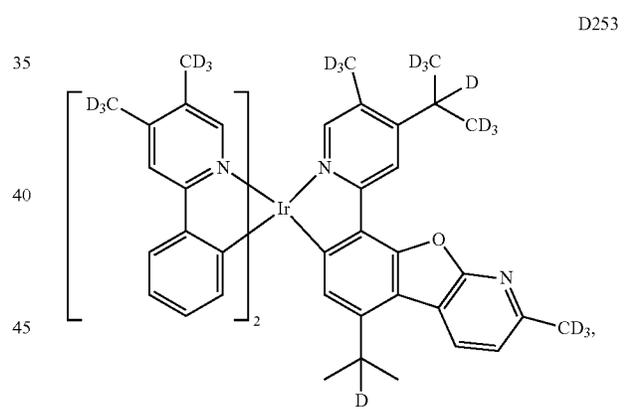
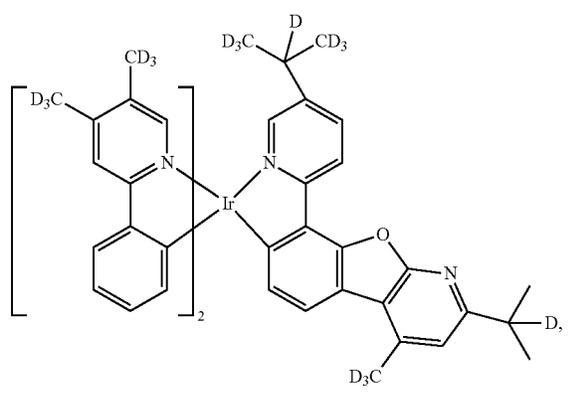
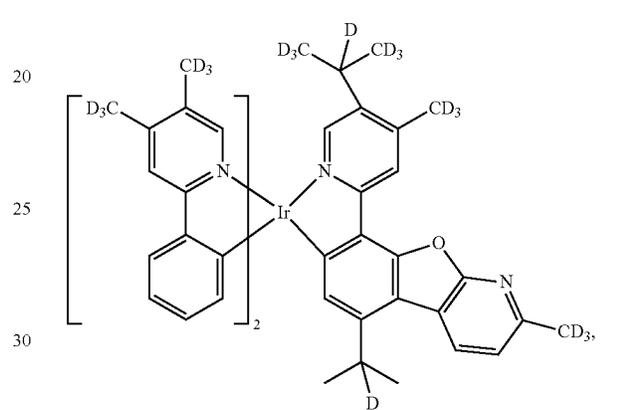
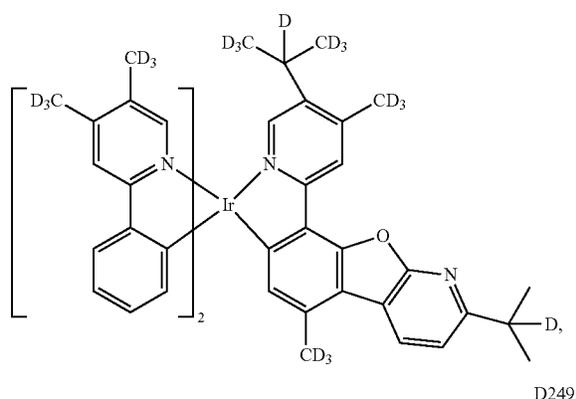
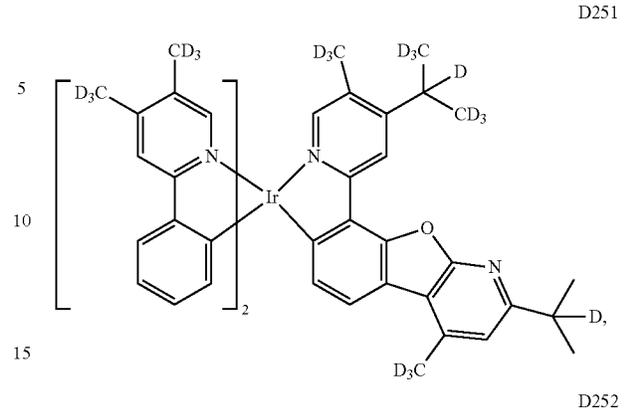
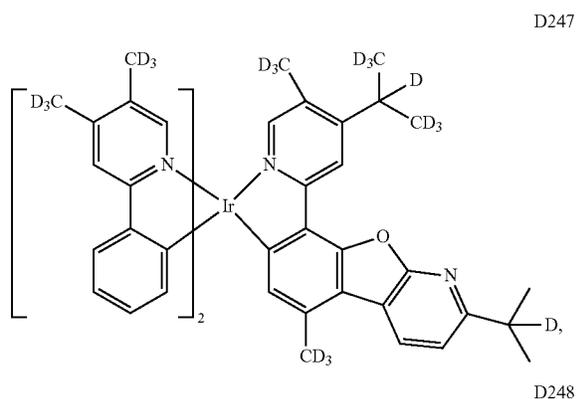
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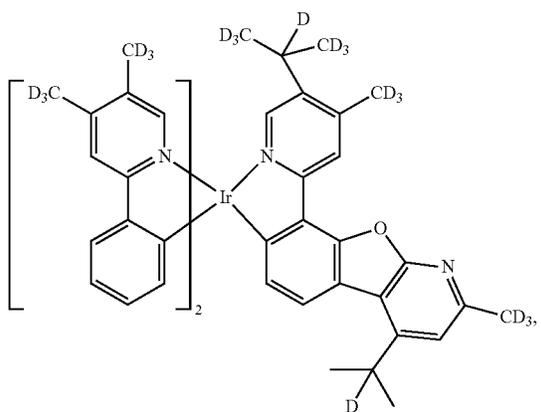
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D255



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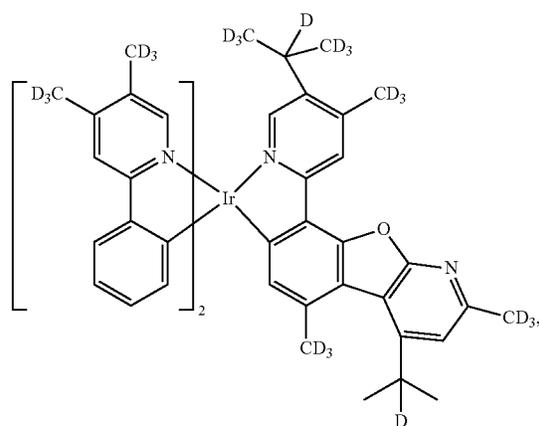
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D258



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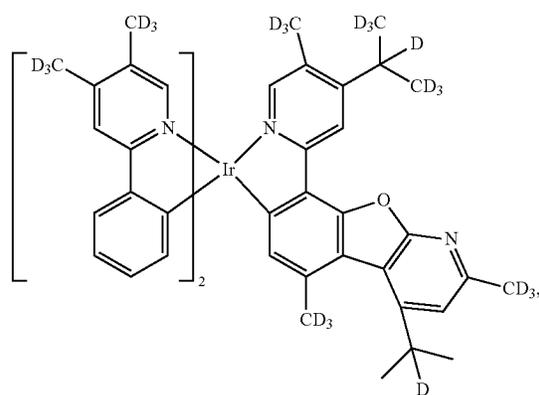
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D256



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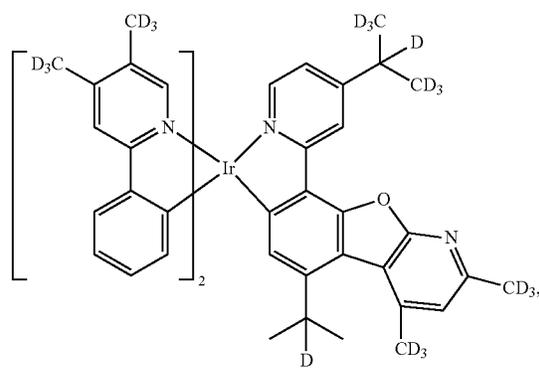
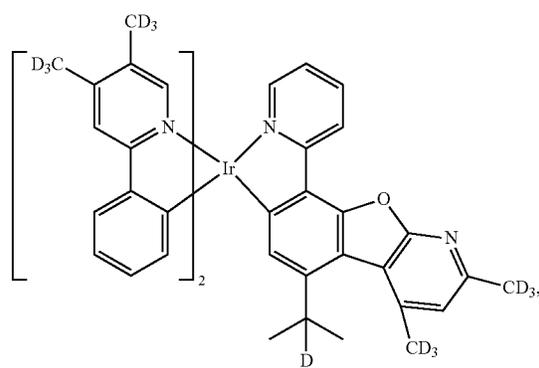
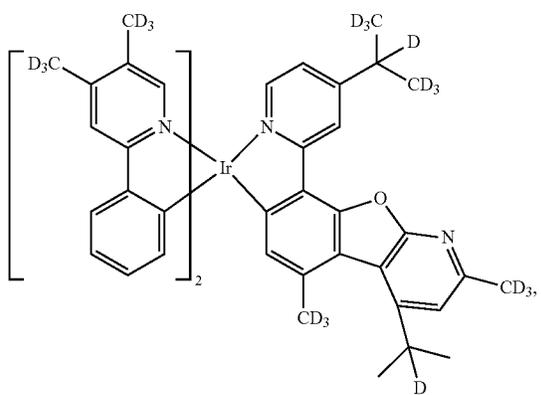
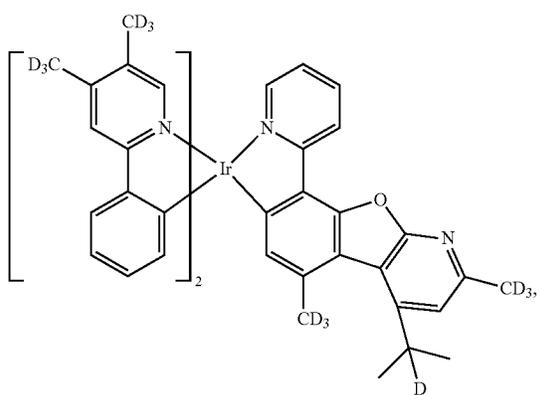
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D259

D260

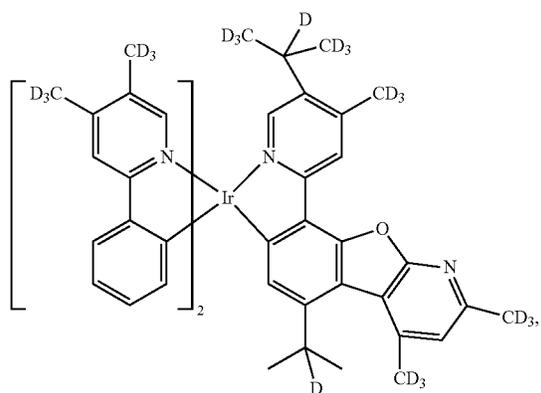
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D262



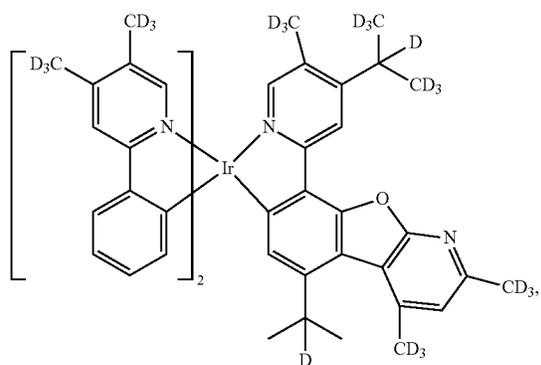
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D263

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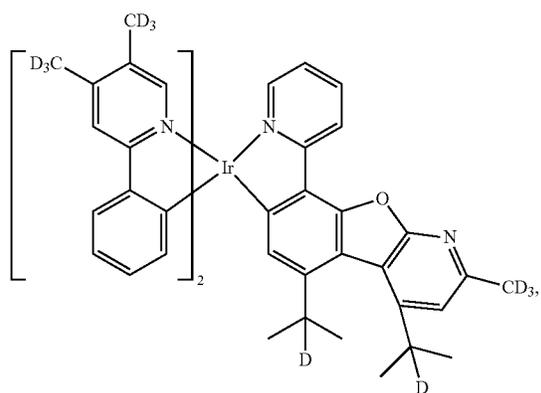


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D264

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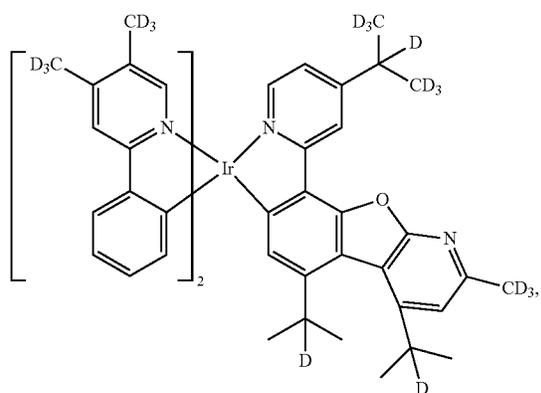


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D265



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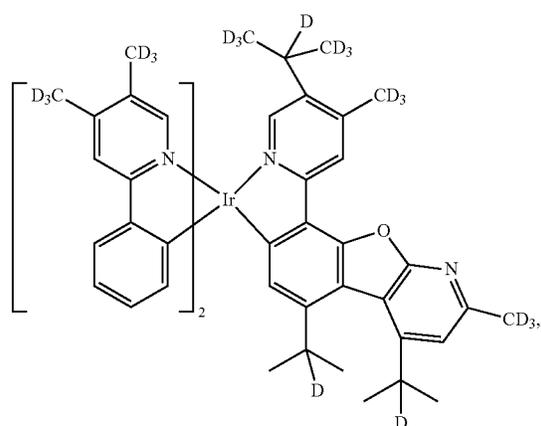
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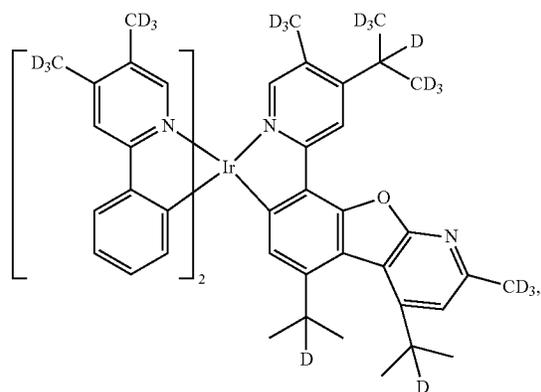
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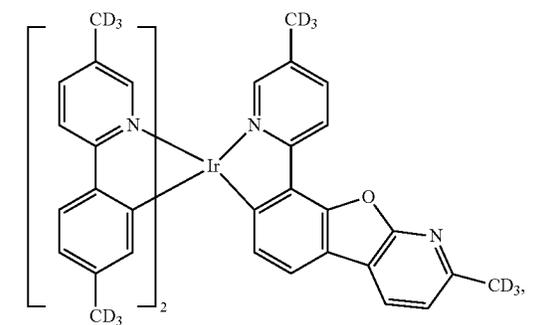
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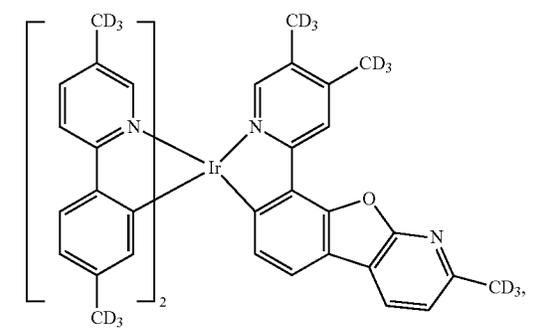
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D268



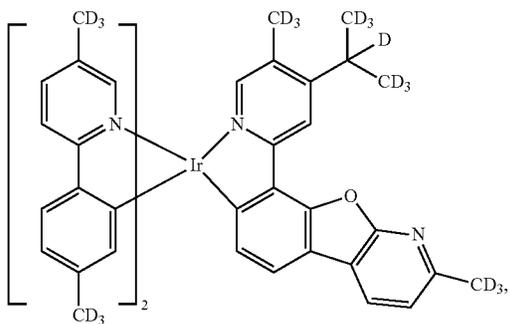
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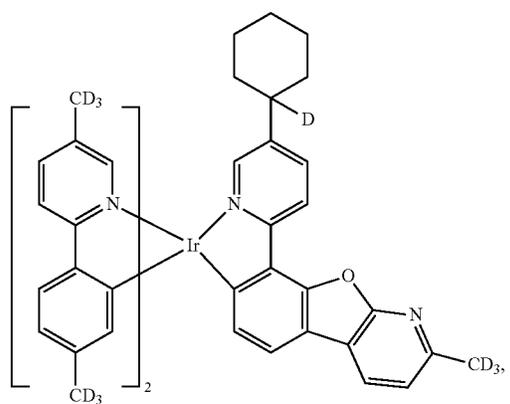
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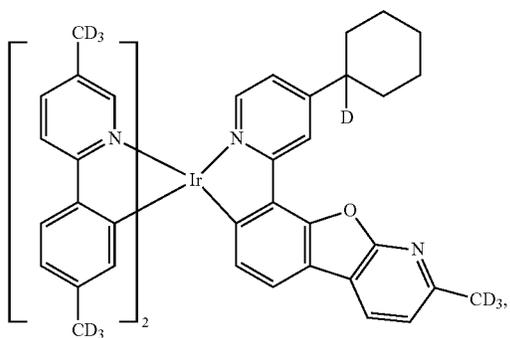
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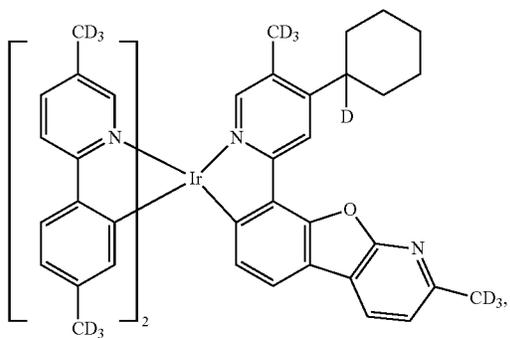
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D272



D273



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D274

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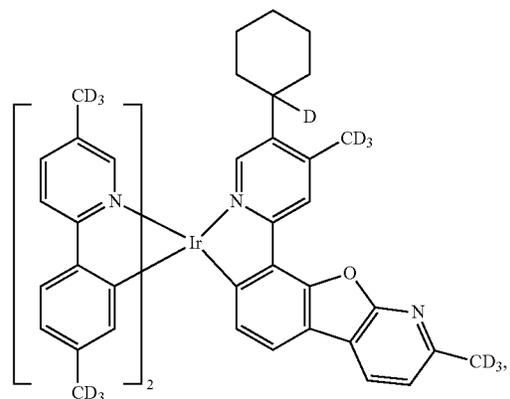
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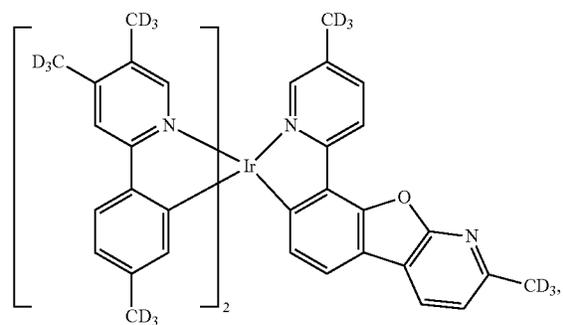
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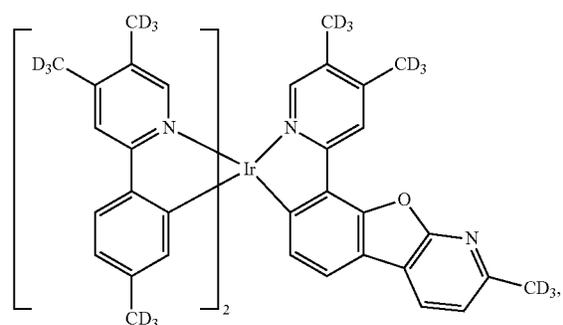
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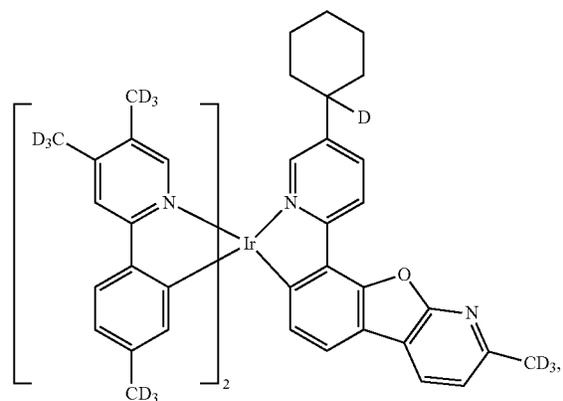
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D276

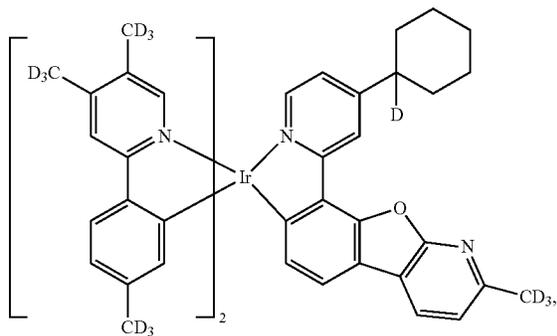


D277



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D278

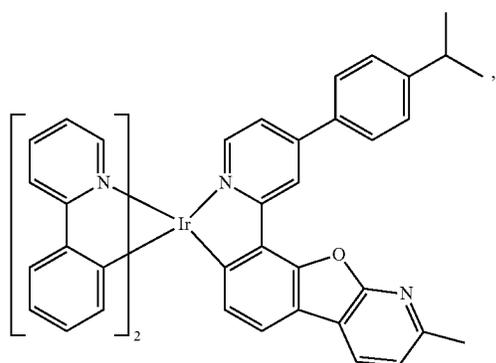


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E1

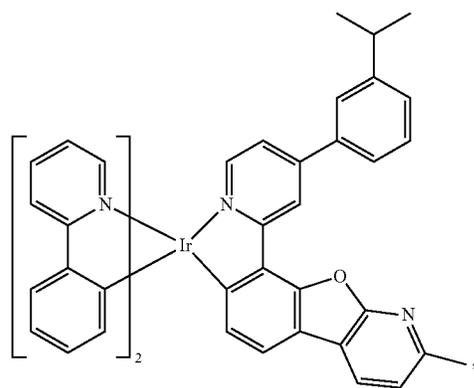


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E2 35

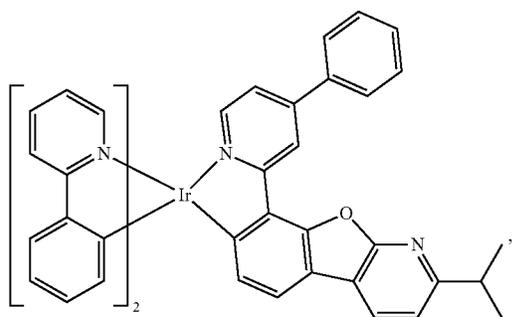


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E3



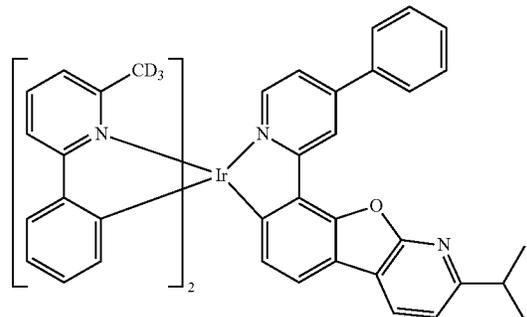
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**322**  
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E4

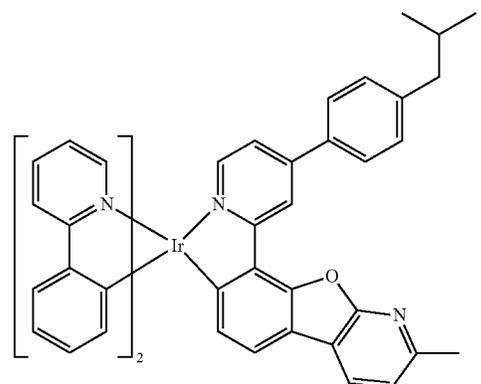


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E5

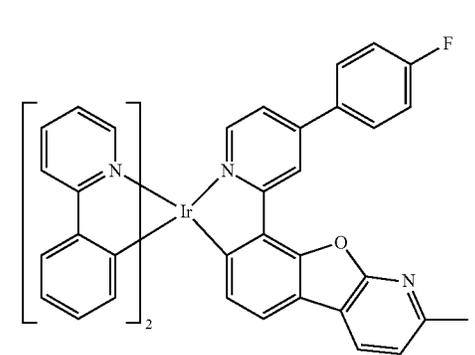


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E6

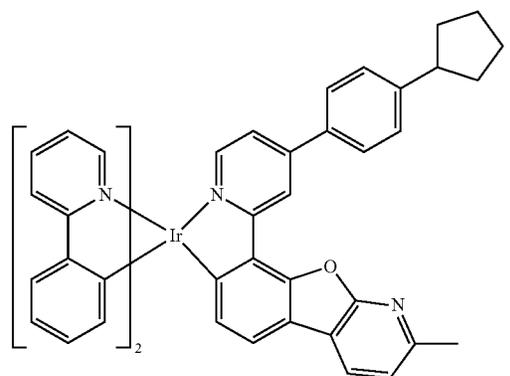


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E7

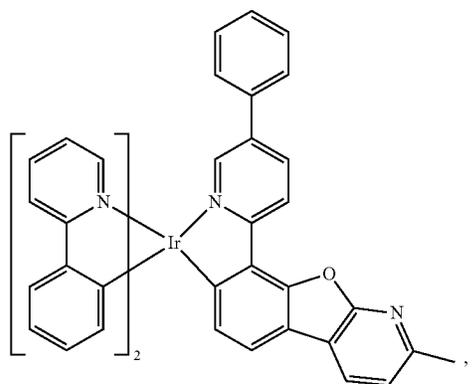
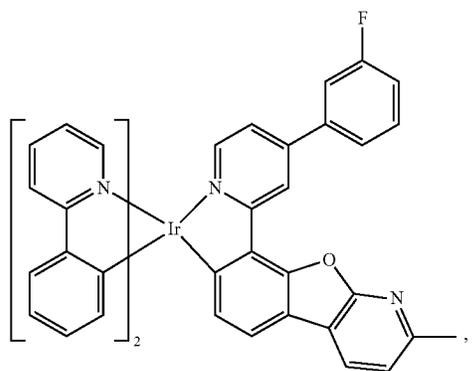
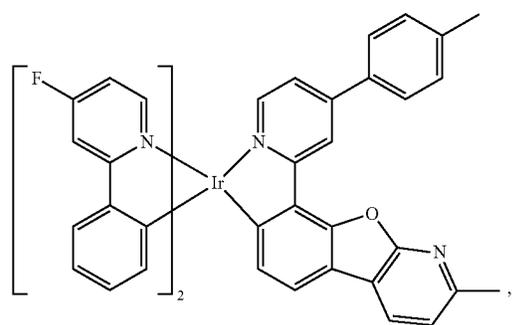
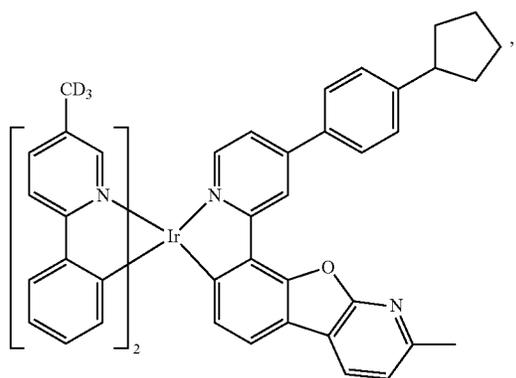


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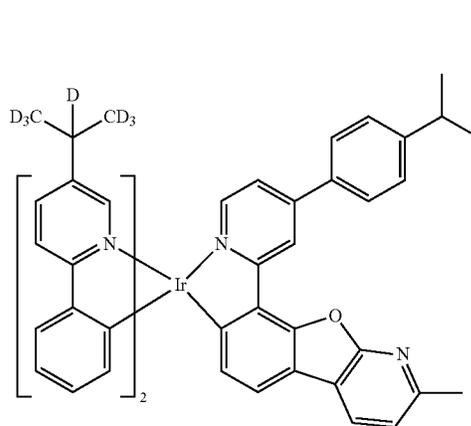
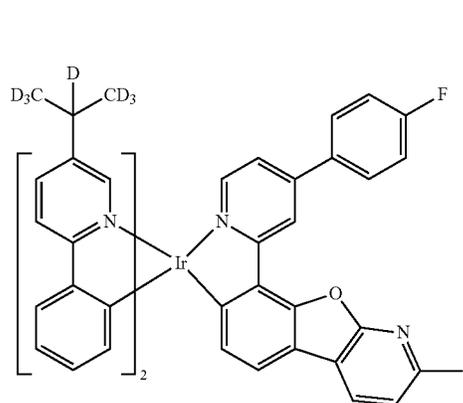
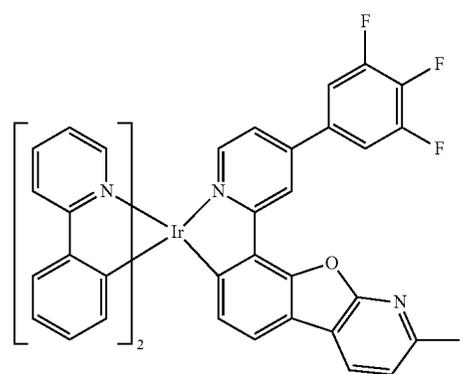
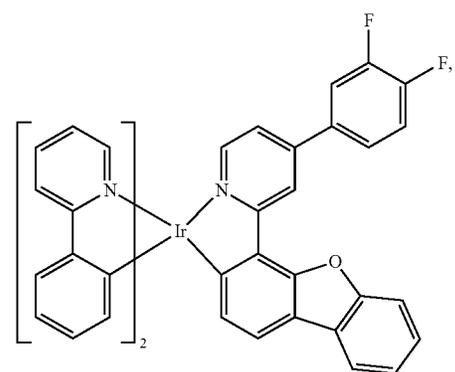
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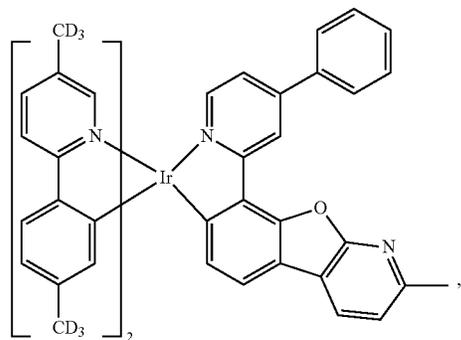
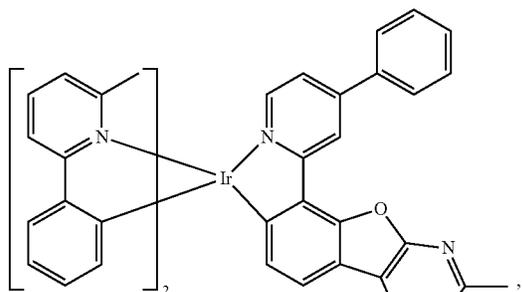
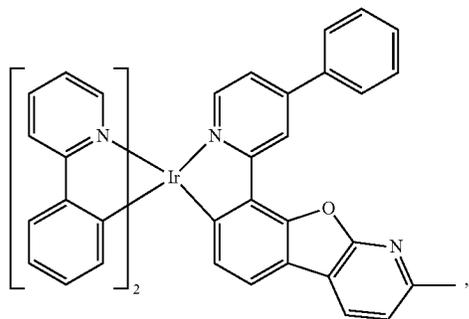
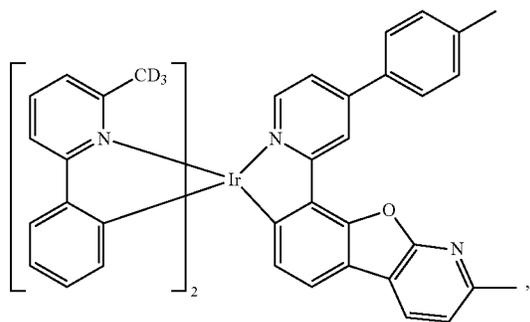
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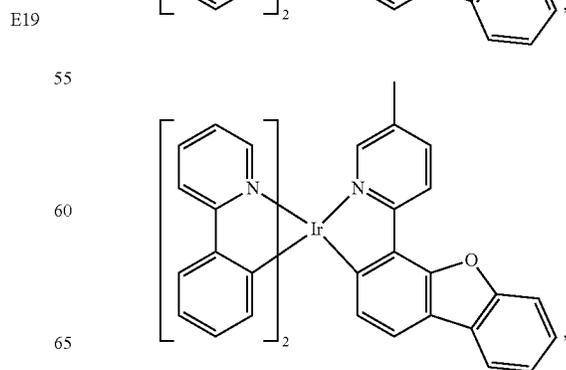
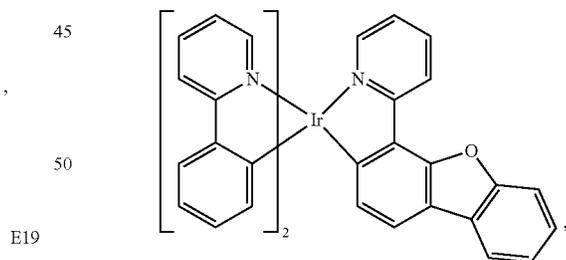
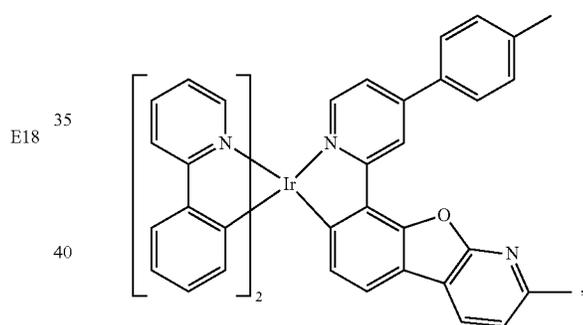
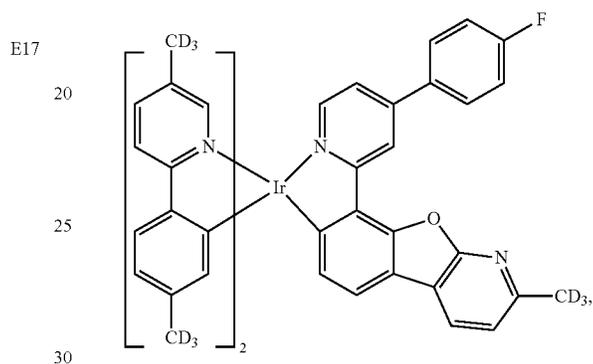
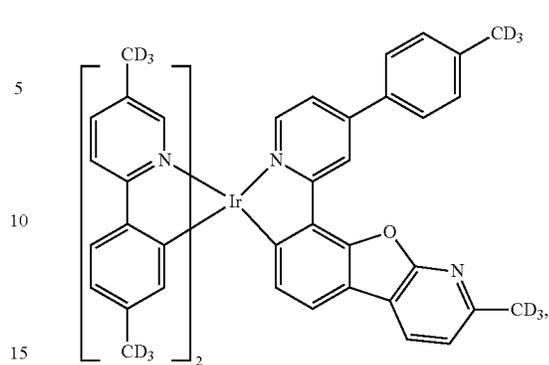
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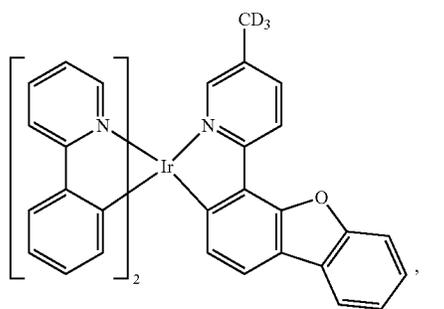
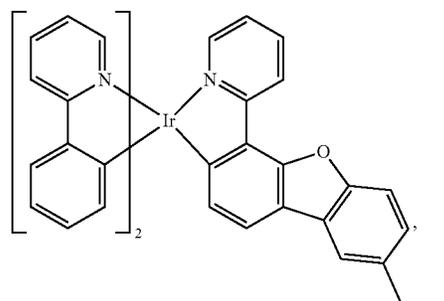
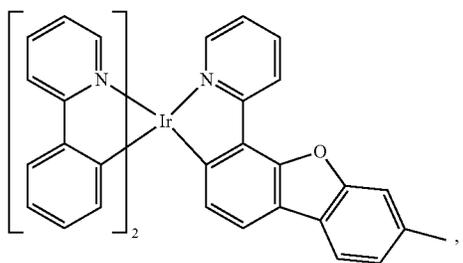
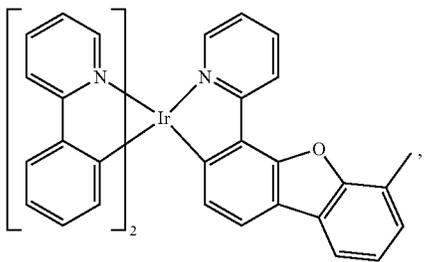
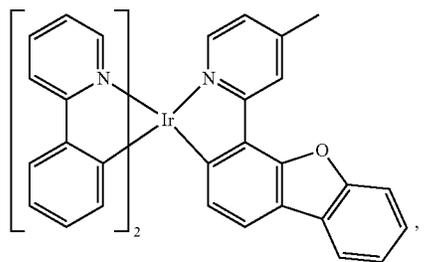
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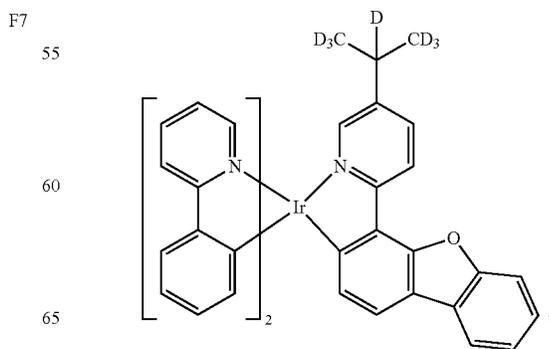
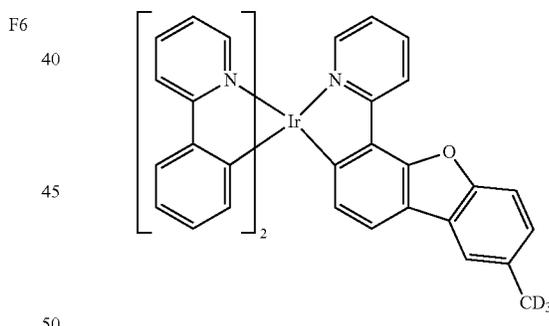
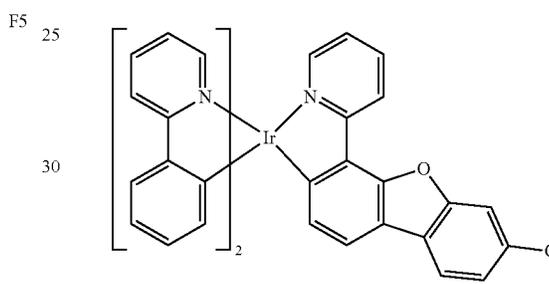
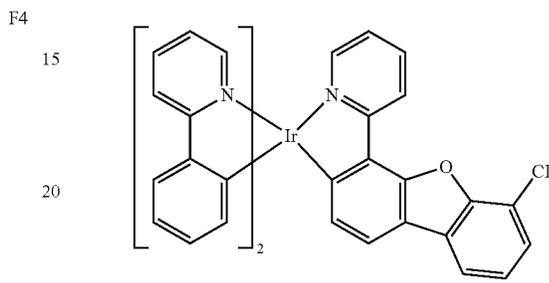
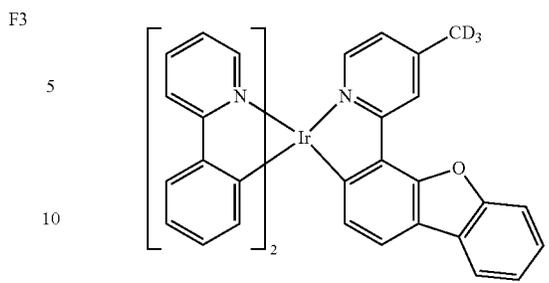
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**327**  
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**328**  
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F8

F9

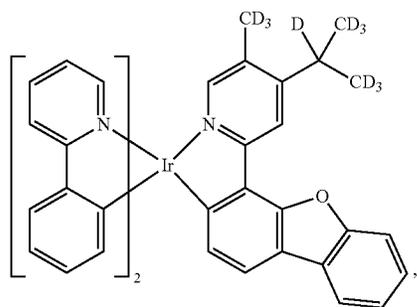
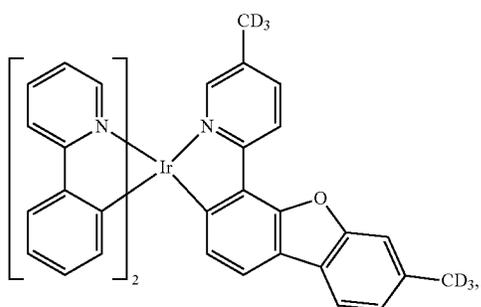
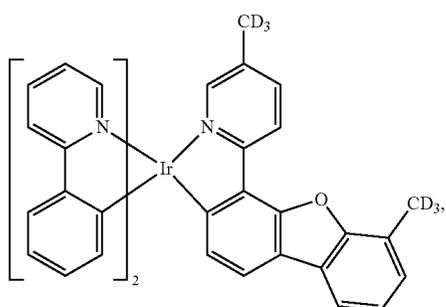
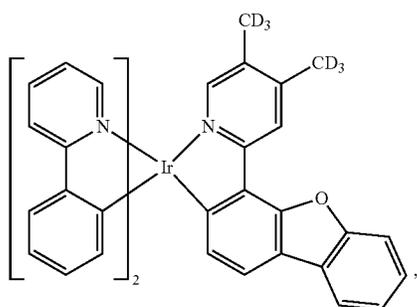
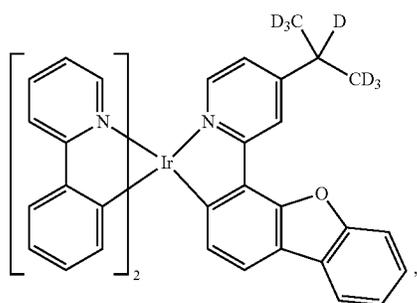
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F12

**329**

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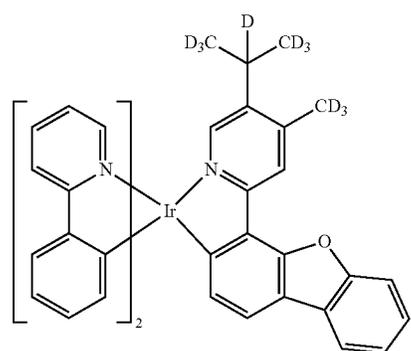


**330**

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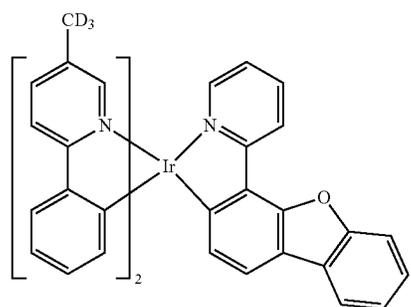
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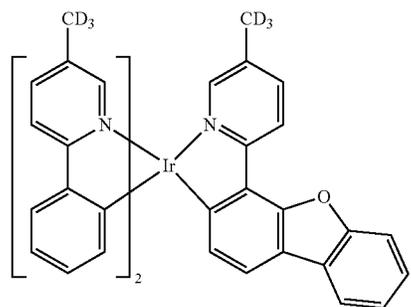
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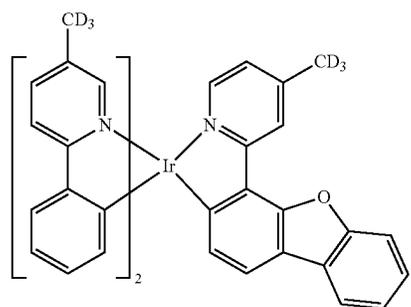
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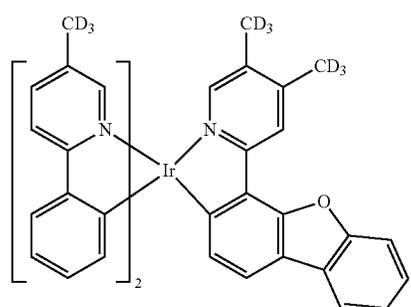
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F17

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F18

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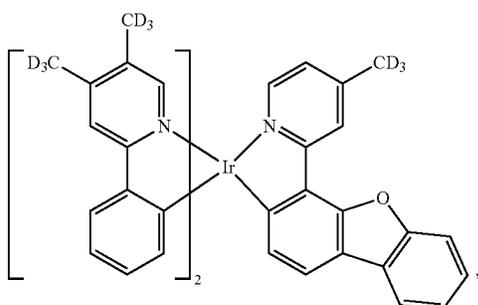
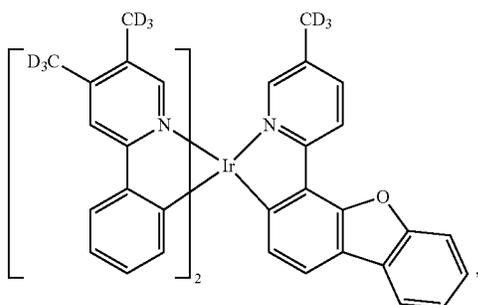
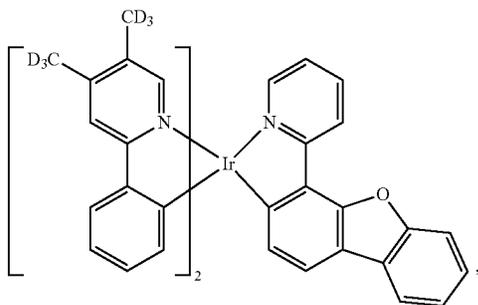
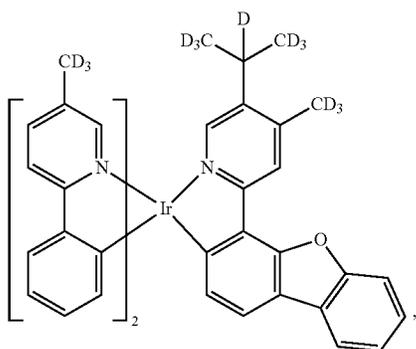
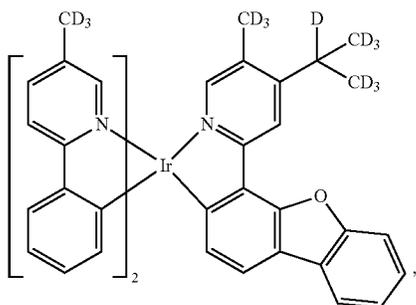
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F22

**331**

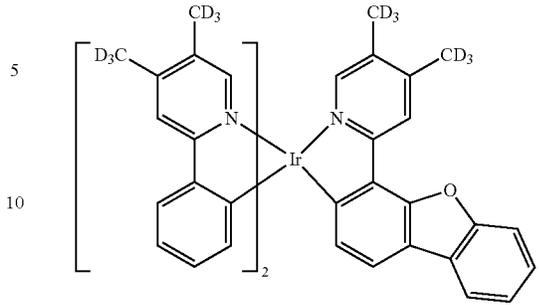
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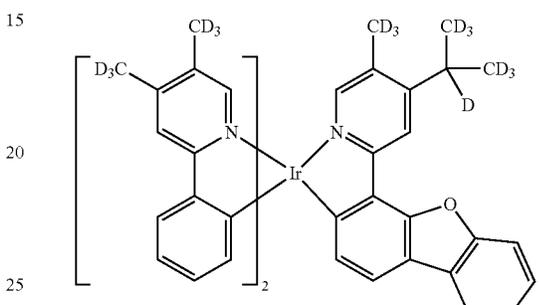
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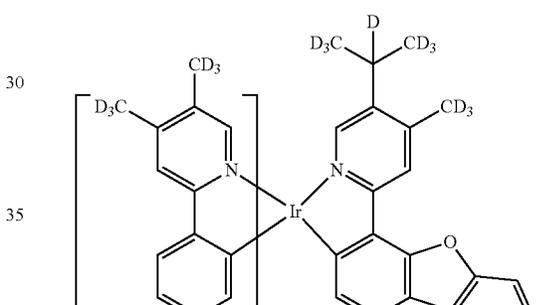


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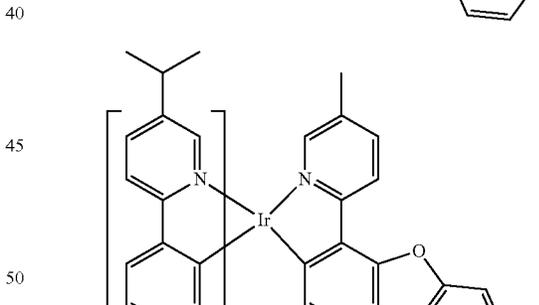
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F25



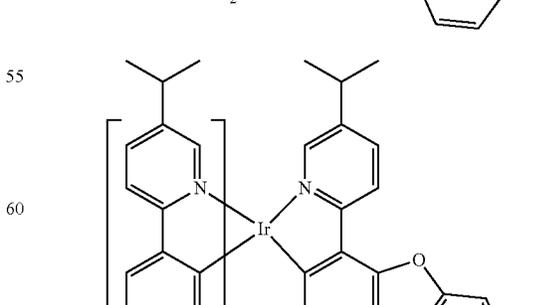
F30

F26



F31

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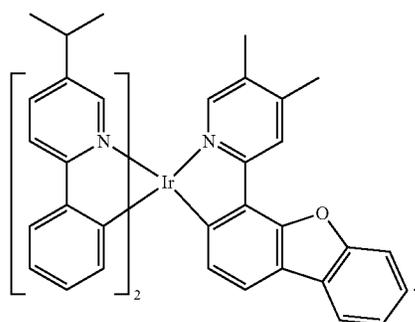
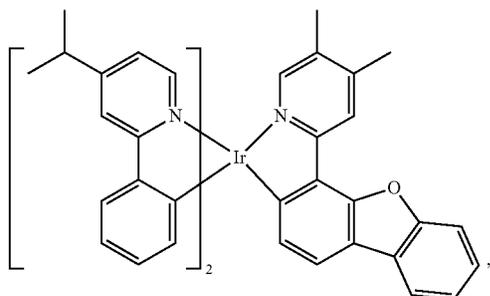
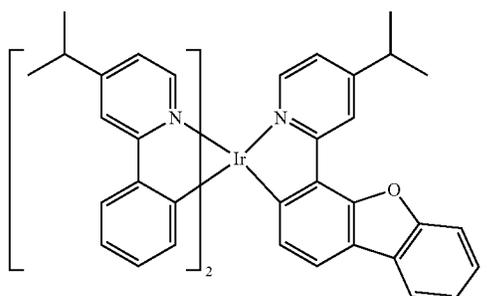
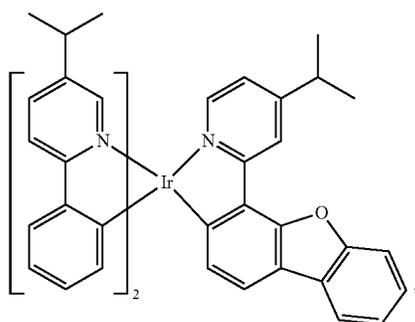


F32

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**333**

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**334**

wherein the first compounds are defined as

F33

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HA26

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F34

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HA30

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F35

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HA33

and

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F36

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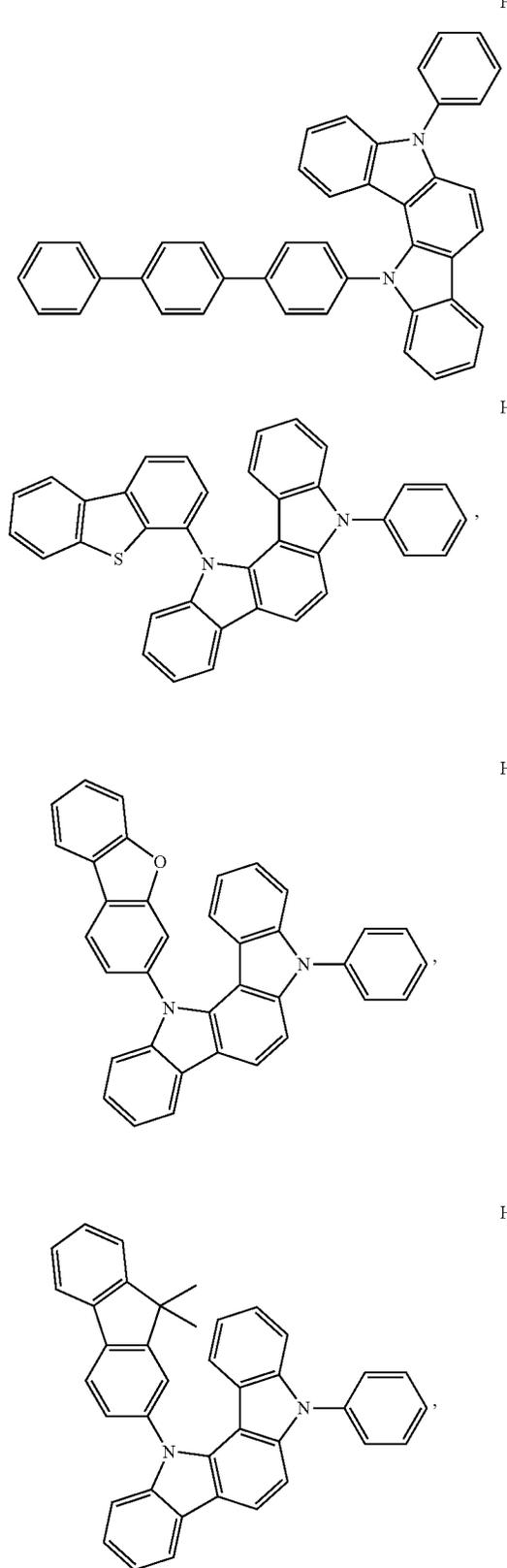
HA34

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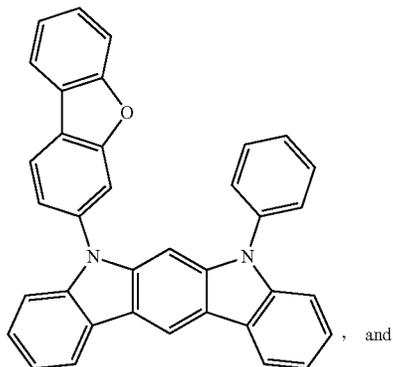
8. The composition comprising a mixture of a first compound and a second compound, wherein the first compound and the second compound are selected in pairs from the group consisting of (Compound HA26, Compound D151), (Compound HA30, Compound D87), (Compound HA33, Compound D13), (Compound HA34, Compound D85), (Compound HA52, Compound D85), and (Compound HA68, Compound D151),

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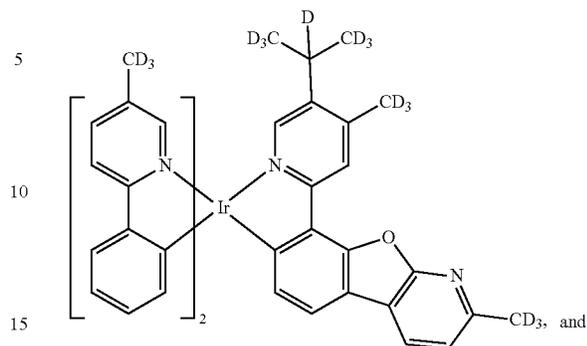


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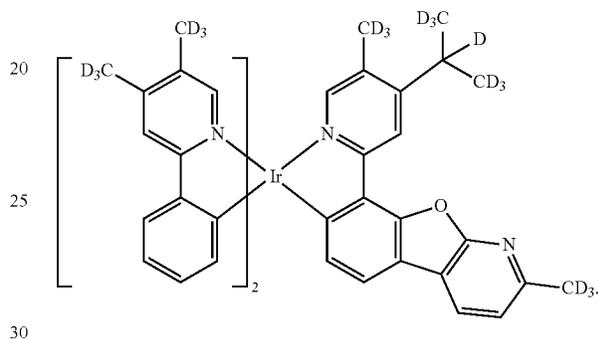


HA52

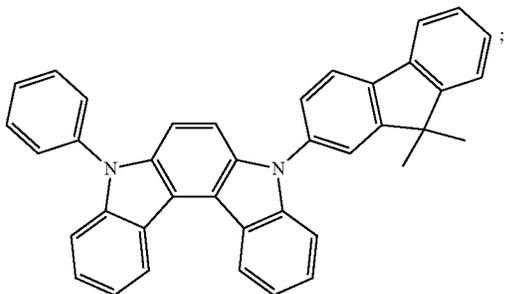
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D87



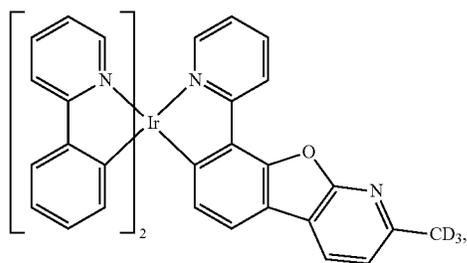
D151



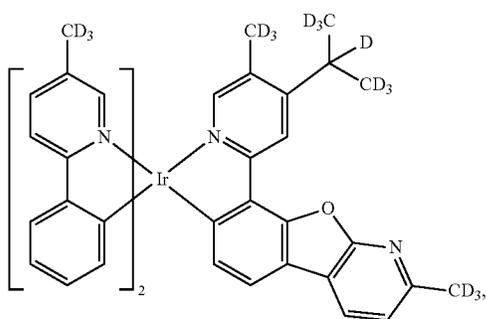
HA68

and

wherein the second compounds are defined as follows:



D13



D85

9. The composition of claim 1, wherein the first compound has an evaporation temperature T1 of 150 to 350° C.; wherein the second compound has an evaporation temperature T2 of 150 to 350° C.; wherein absolute value of T1-T2 is less than 20° C.; wherein the first compound has a concentration C1 in said mixture and a concentration C2 in a film formed by evaporating the mixture in a vacuum deposition tool at a constant pressure between 1×10<sup>-6</sup> Torr to 1×10<sup>-9</sup> Torr, at a 2Å/sec deposition rate on a surface position at a predefined distance away from the mixture being evaporated; and

wherein absolute value of (C1-C2)/C1 is less than 5%.

10. The composition of claim 1, wherein the first compound has a vapor pressure of P1 at T1 at 1 atm, the second compound has a vapor pressure of P2 at T2 at 1 atm; and wherein the ratio of P1/P2 is within the range of 0.90 to 1.10.

11. The composition of claim 1, wherein first compound has a first mass loss rate and the second compound has a second mass loss rate, wherein the ratio between the first mass loss rate and the second mass loss rate is within the range of 0.90 to 1.10.

12. A method for fabricating an organic light emitting device, the method comprising:

placing a premixed VTE evaporation source in an evaporation crucible;

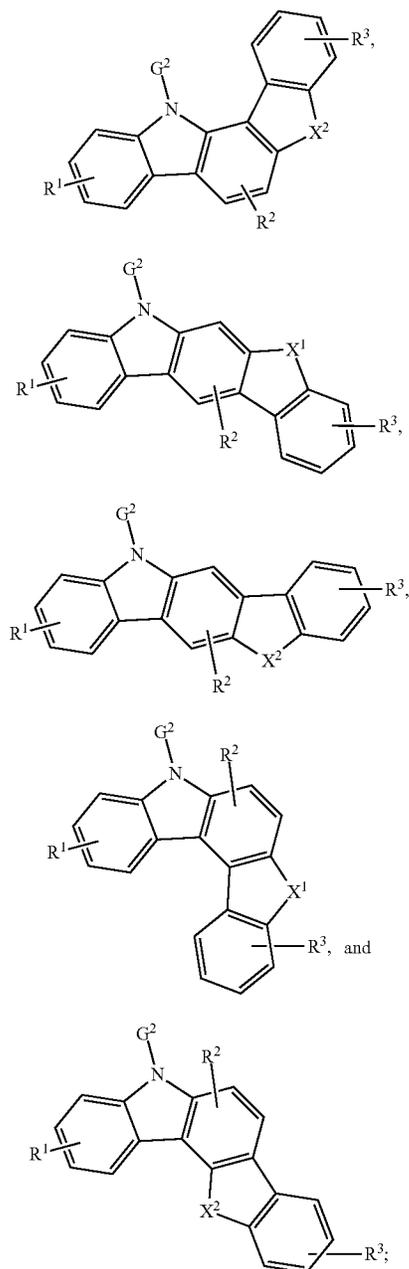
providing a substrate having a first electrode disposed thereon;

depositing a first organic layer over the first electrode by evaporating the premixed VTE evaporation source from the evaporation crucible, wherein the premixed VTE evaporation source is a mixture of a first compound and a second compound in a vacuum deposition tool at a constant pressure between 1×10<sup>-6</sup> Torr to

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337

$1 \times 10^{-9}$  Torr, at a  $2 \text{ \AA}/\text{sec}$  deposition rate on a surface position at a predefined distance away from the mixture being evaporated; and depositing a second electrode over the first organic layer; wherein the first compound is selected from the group consisting of:



wherein  $X^1$  and  $X^2$  are each independently selected from the group consisting of  $CR^4R^5$ , O, S and Se; wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution; wherein  $R^1$  to  $R^3$  each independently represent mono to the possible maximum number of substitution, or no substitution;

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wherein (i)  $G^2$  comprises a moiety selected from the group consisting of dibenzofuran, dibenzothiophene, dibenzoselenophene, fluorene, triphenylene, and combinations thereof, or

(ii)  $G^2$  comprises a moiety selected from the group consisting of phenanthroline, azadibenzofuran, azadibenzothiophene, azadibenzoselenophene, azafluorene, aza-triphenylene, and combinations thereof;

wherein  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ , and  $R^5$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, acyl, carbonyl, carboxylic acid, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein any two adjacent substituents can optionally join or fuse into a ring;

wherein at least one of option (a) or option (b) is true:

(a)  $X^1$  or  $X^2$  is present and represents Se;

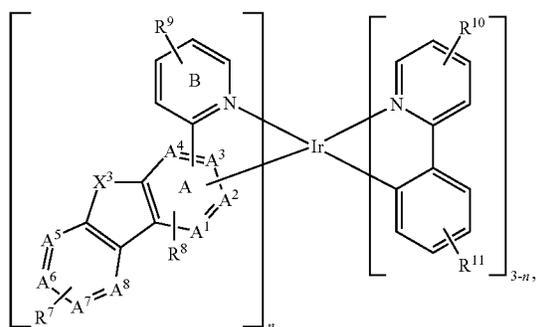
(b)(i) the first compound has the structure of GH2 or GH3, or (1)(ii) the first compound has a structure of GH1, GH4, or GH5, and two  $le$  are not joined to form a ring, and

(2) at least one of  $R^1$  and  $R^3$  is unsubstituted, and

(3)  $G^2$  is selected from the group consisting of dibenzoselenophene, phenanthroline, azadibenzofuran, azadibenzoselenophene, azafluorene, and combinations thereof;

with the proviso that none of  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ , or  $R^5$  is triphenylene;

wherein the second compound has a formula  $Ir(L_A)_n(L_B)_{3-n}$ , and having the structure according to Formula II



wherein each  $A^1$ ,  $A^2$ ,  $A^3$ ,  $A^4$ ,  $A^5$ ,  $A^6$ ,  $A^7$ , and  $A^8$  comprise carbon or nitrogen;

wherein ring B is bonded to ring A through a C—C bond;

wherein the iridium is bonded to ring A through a Ir—C bond;

wherein  $X^3$  is selected from a group consisting of O, S and Se;

wherein  $R^7$  to  $R^{11}$  each independently represent mono to the possible maximum number of substitution, or no substitution;

wherein  $R^7$  to  $R^{11}$  are each independently selected from the group consisting of hydrogen, deuterium, halogen, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl,

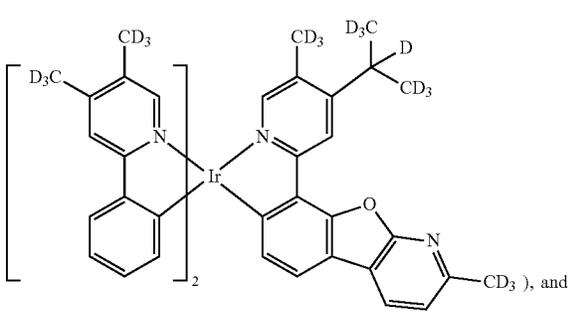
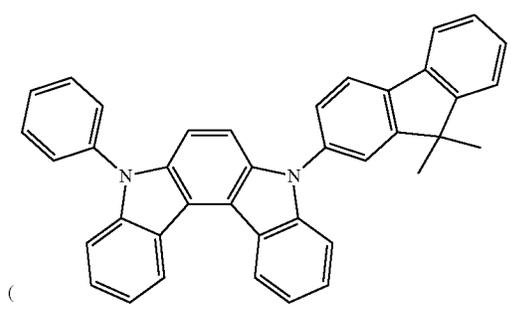
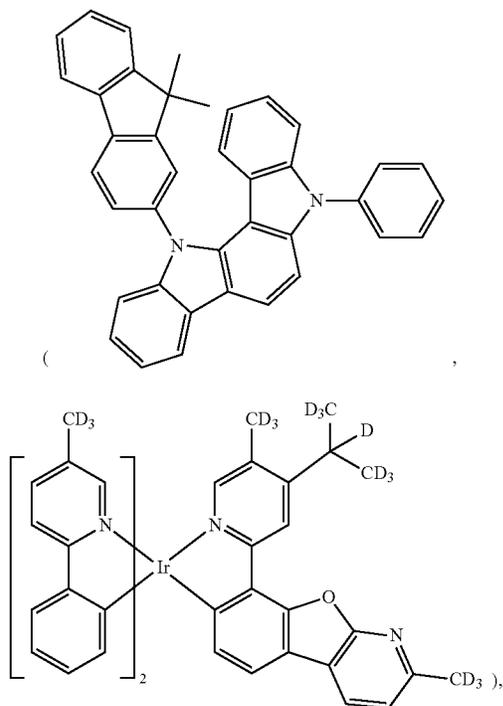
339

carboxylic acid, ester, nitrile, isonitrile, sulfonyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and

wherein any two adjacent substituents can optionally join or fuse into a ring; and

wherein n is an integer from 1 to 3.

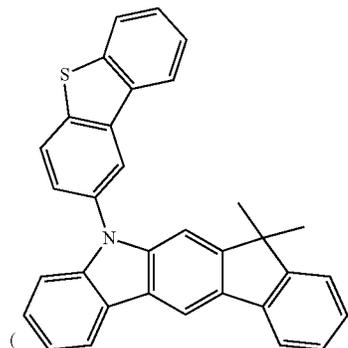
13. A composition comprising a first compound and a second compound selected in pairs from the group consisting of



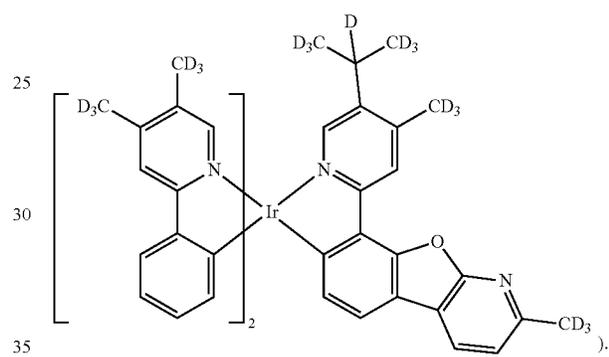
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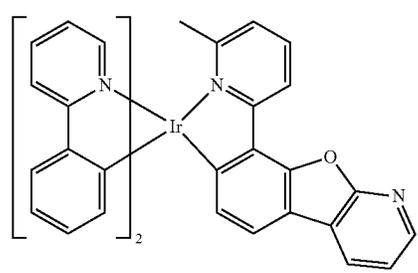
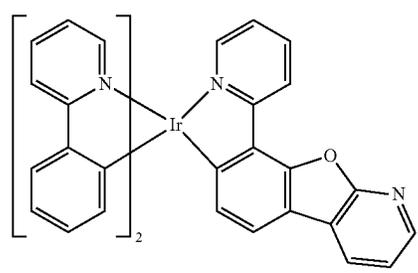
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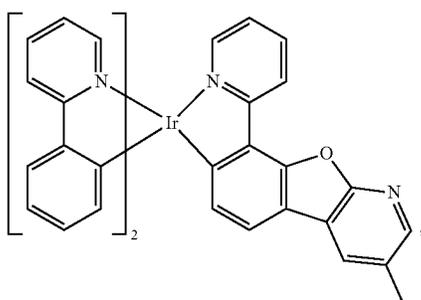
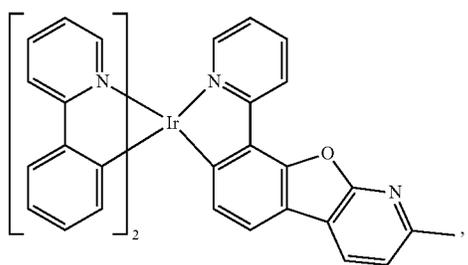
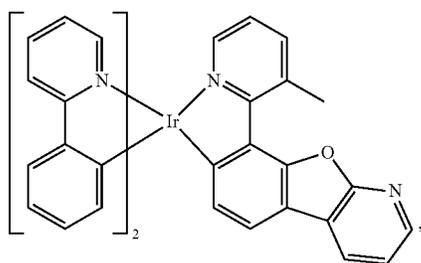
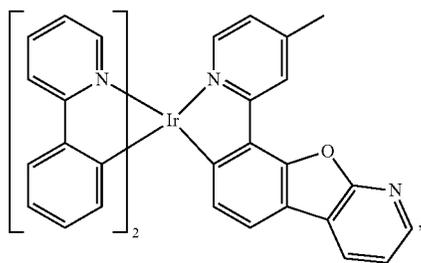
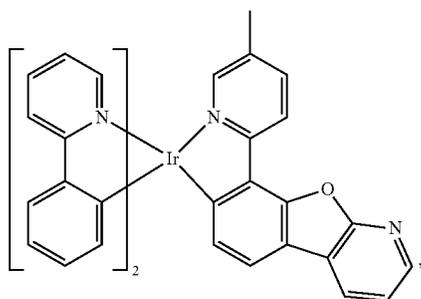


14. The composition of claim 3, wherein the second compound is selected from the group consisting of:



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**342**

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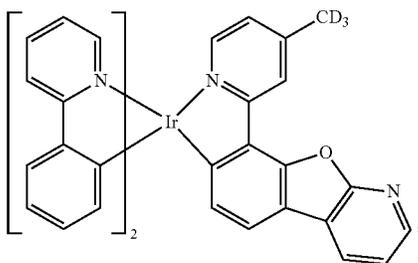
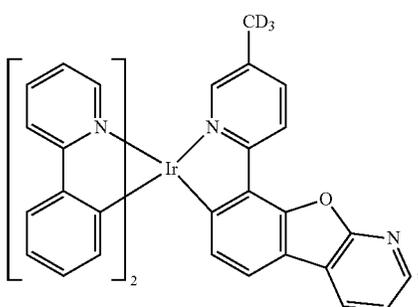
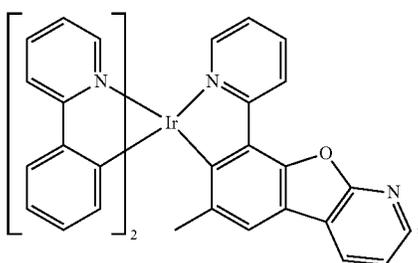
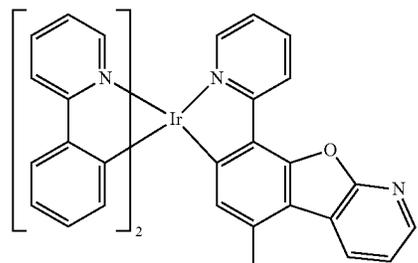
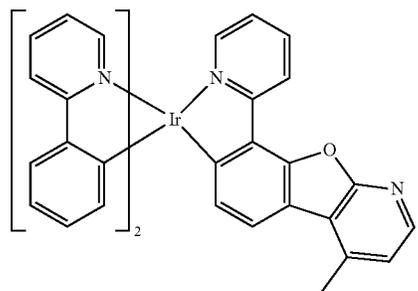
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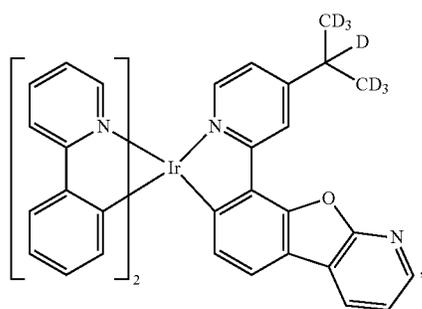
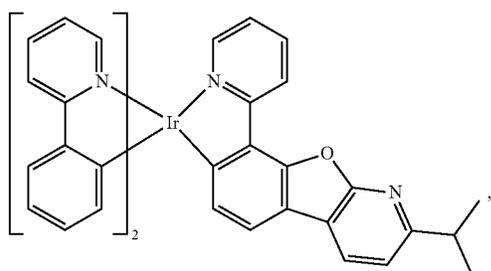
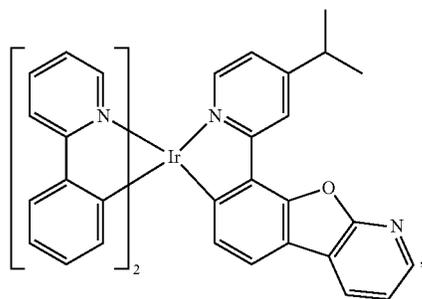
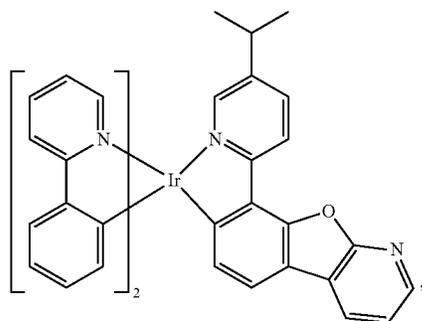
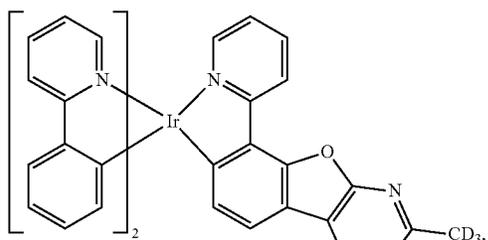
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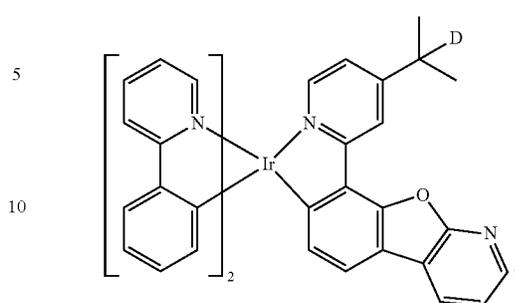
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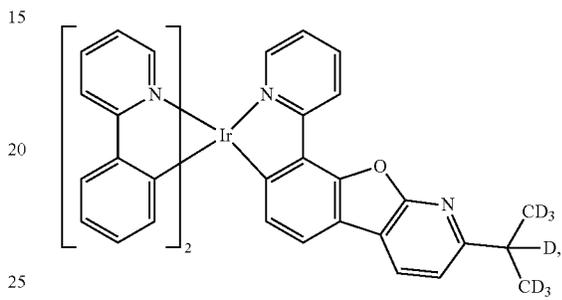
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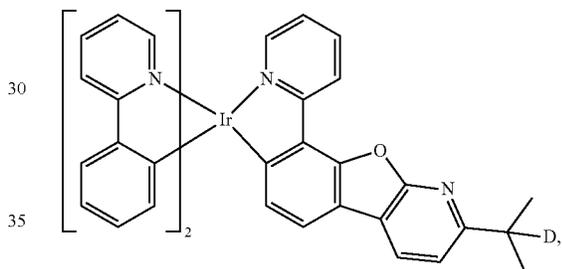
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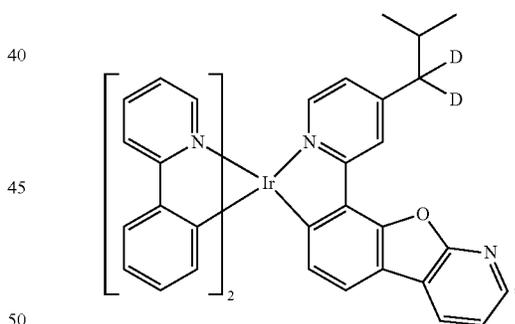
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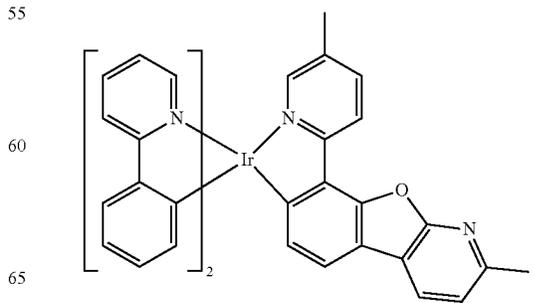
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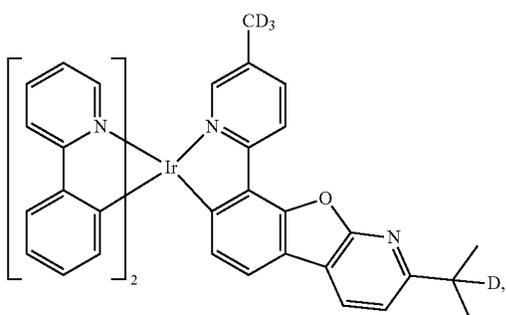
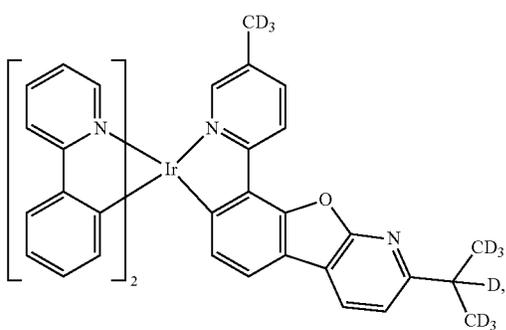
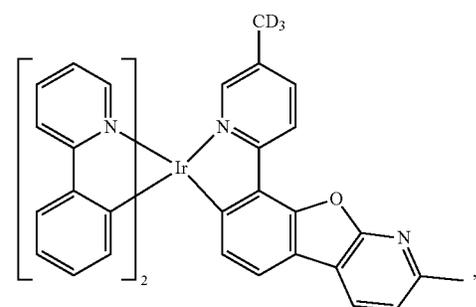
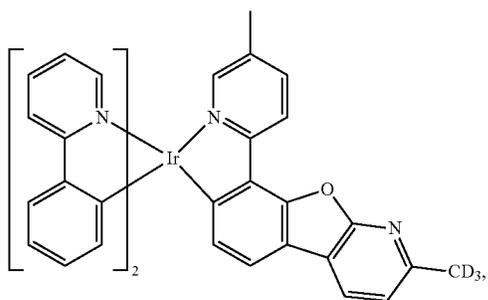
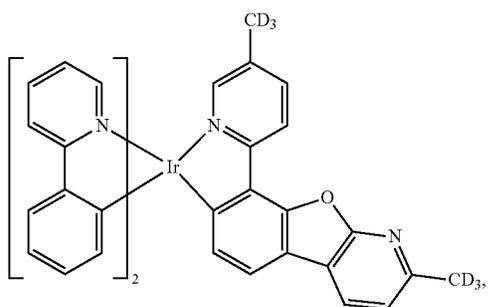
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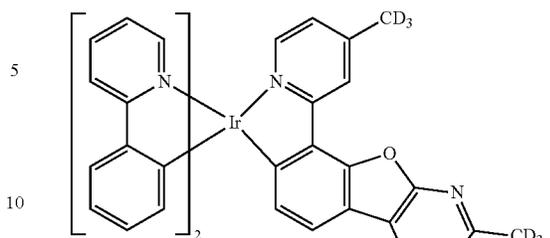
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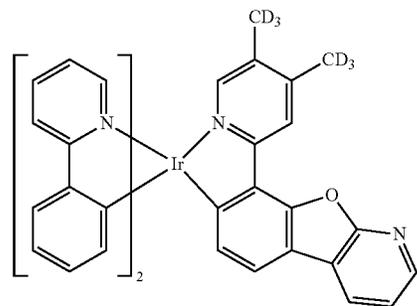
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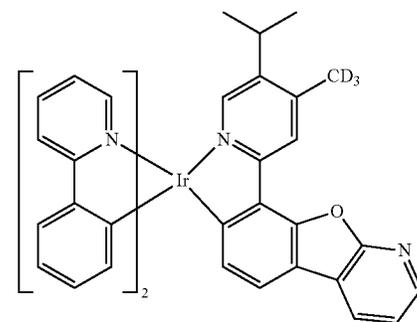


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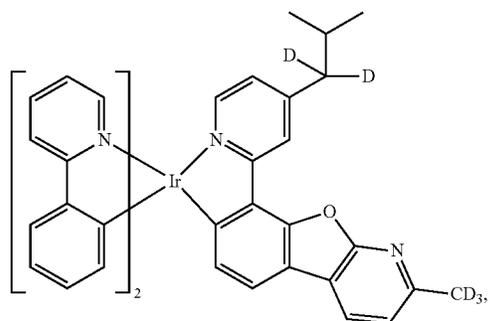
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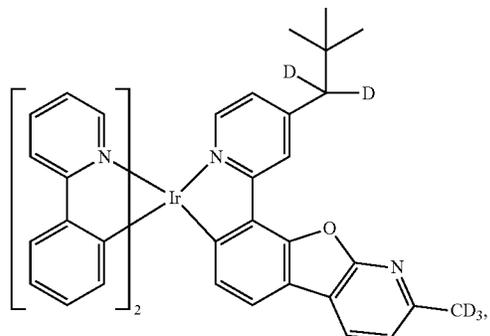
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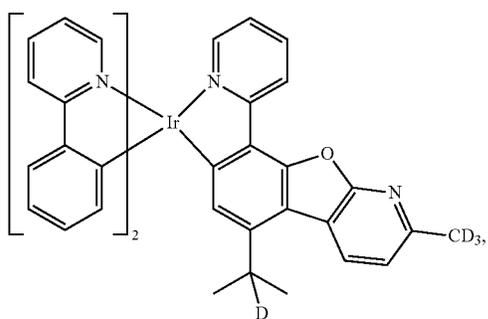
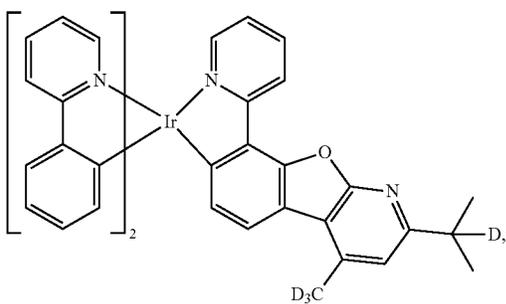
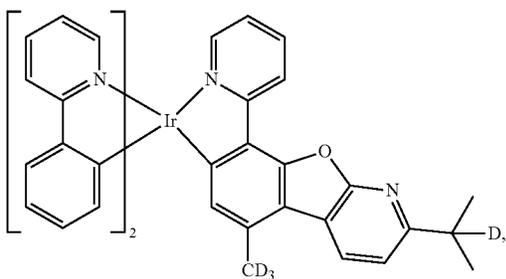
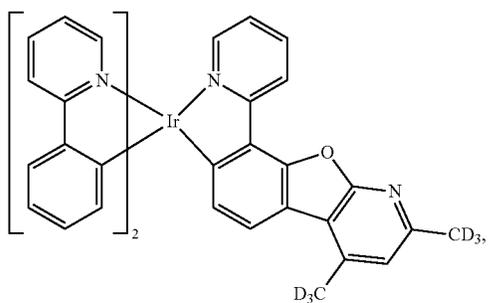
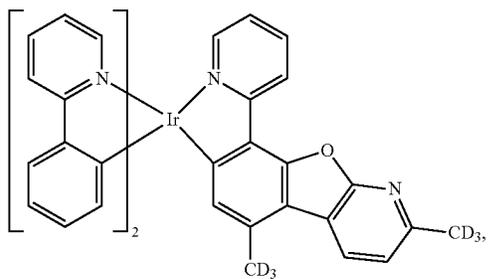
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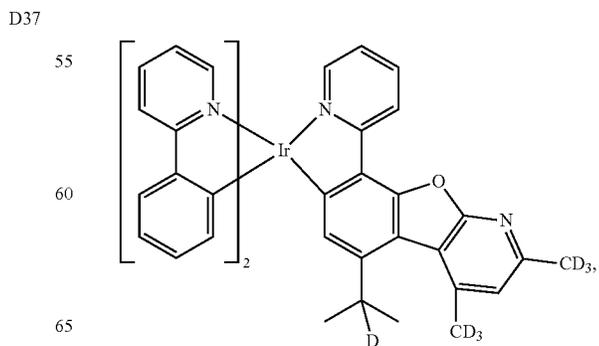
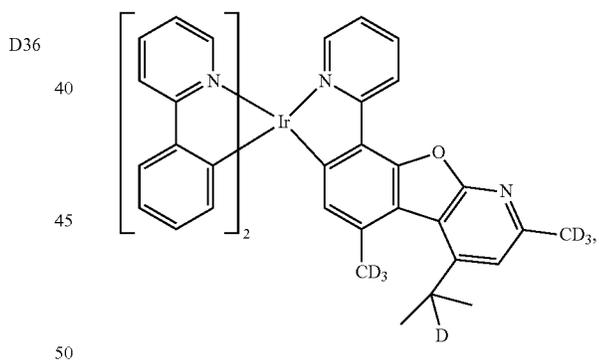
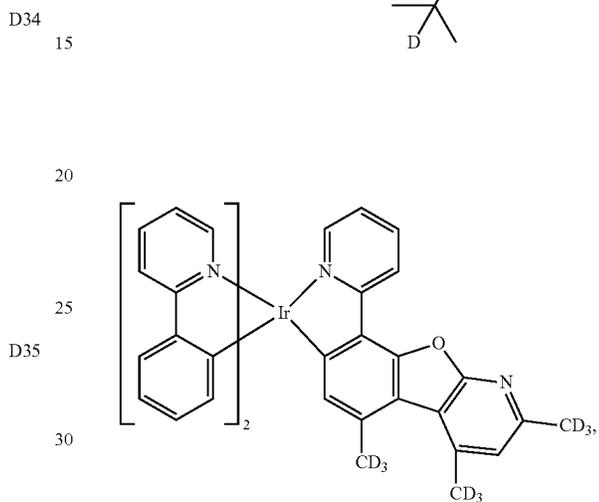
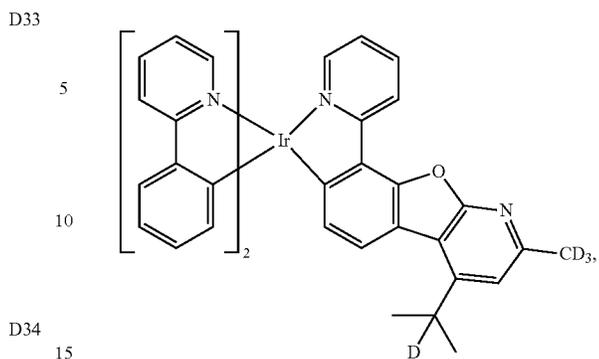


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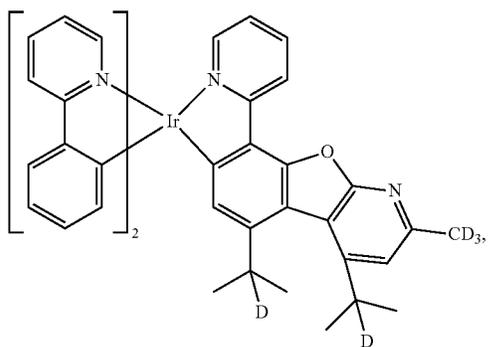


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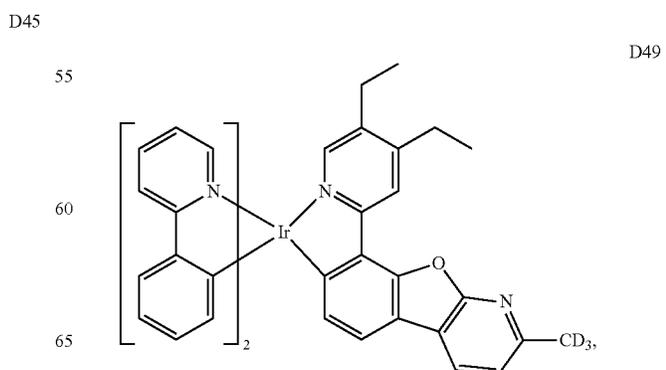
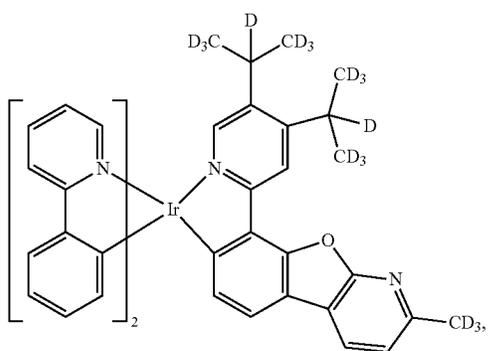
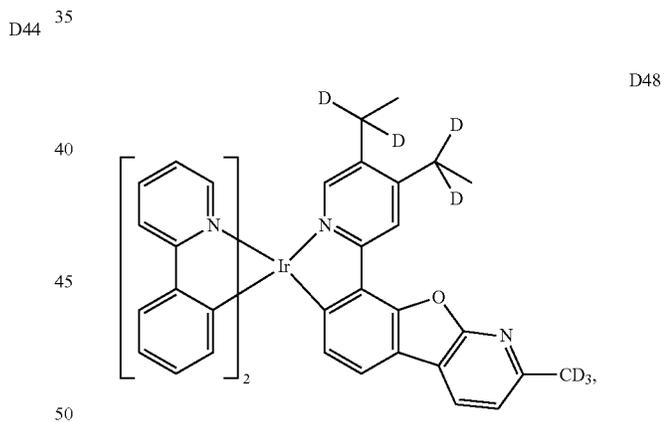
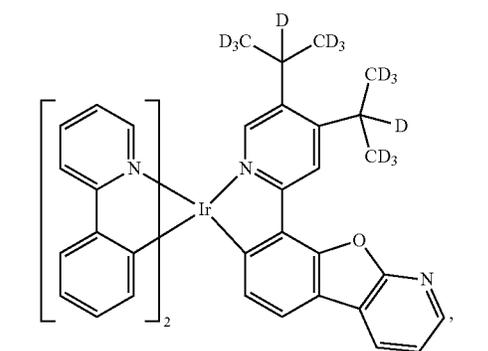
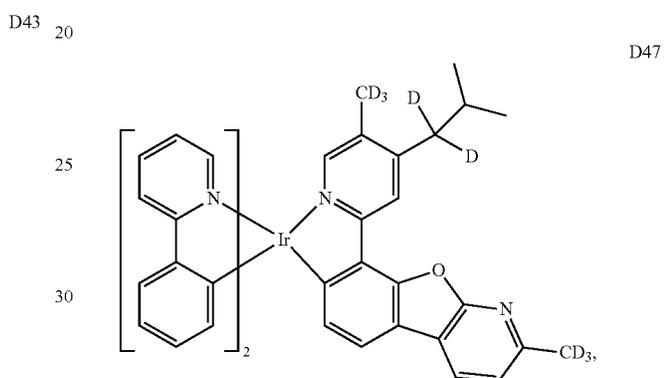
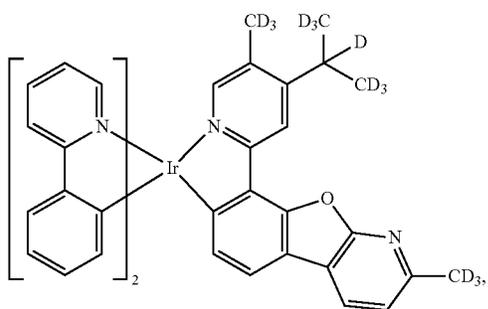
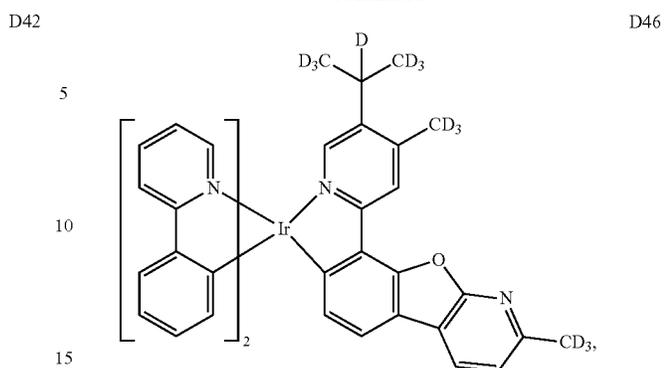
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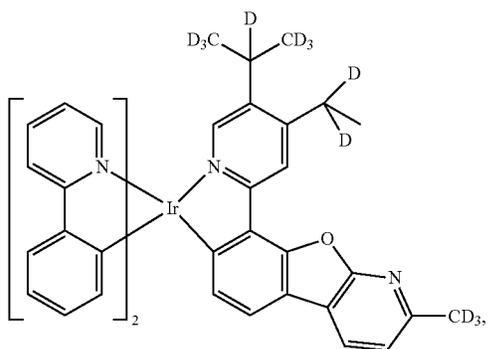
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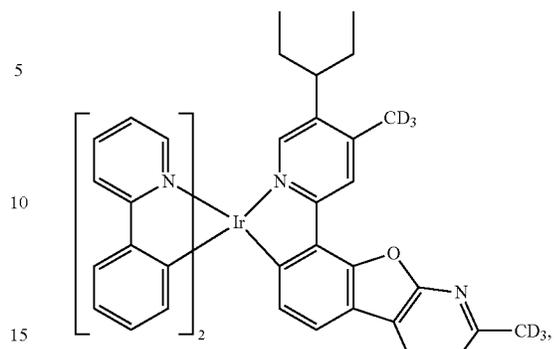
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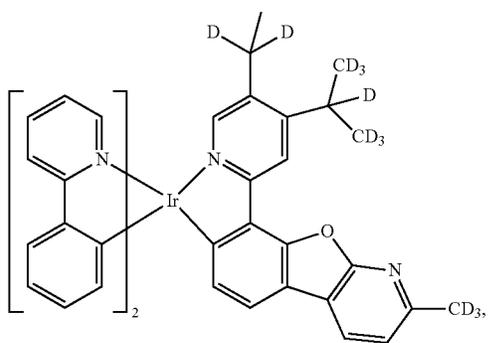


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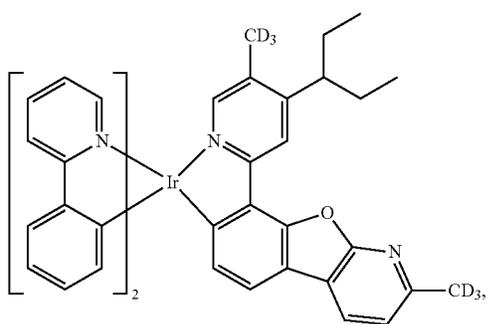
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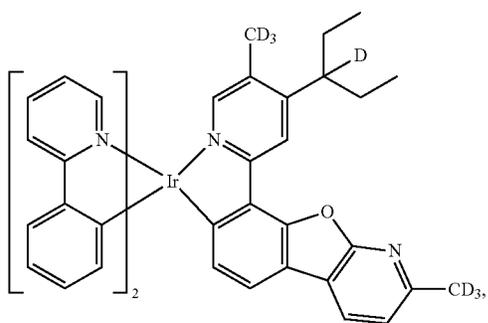


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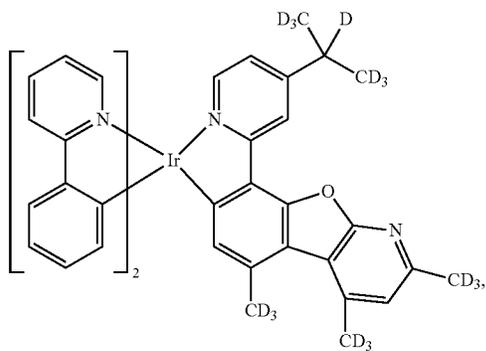
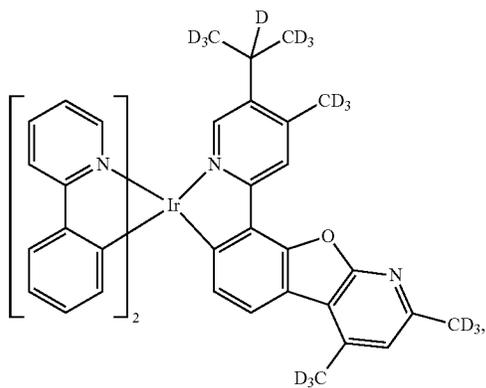
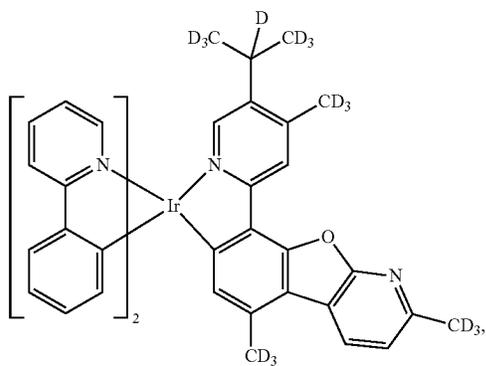
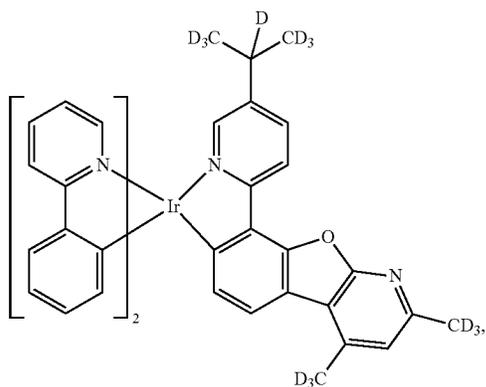
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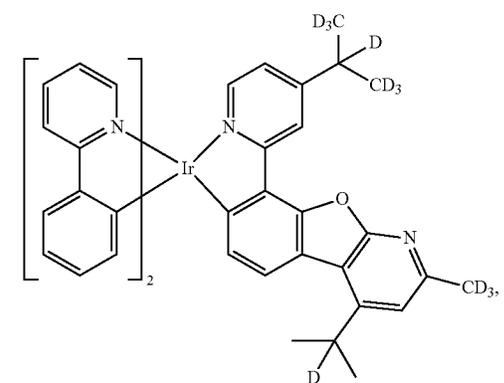
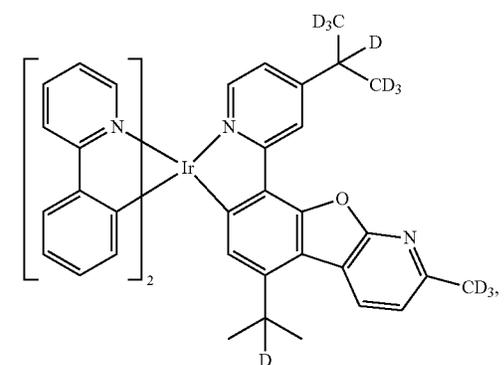
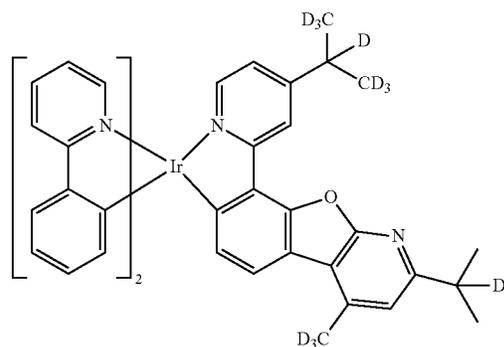
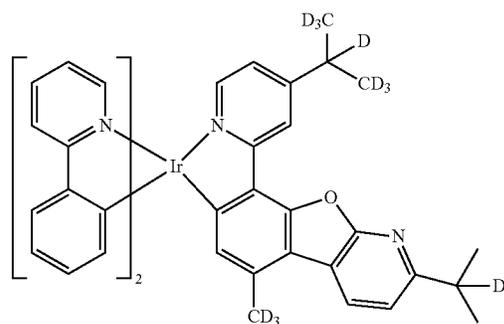
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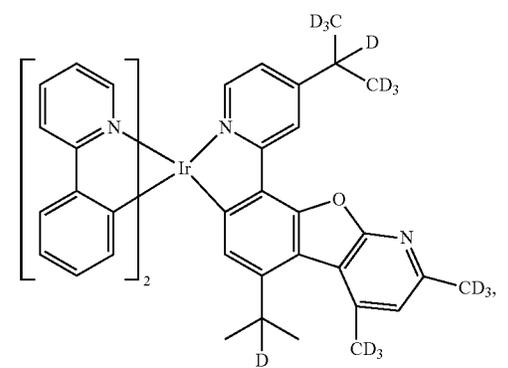
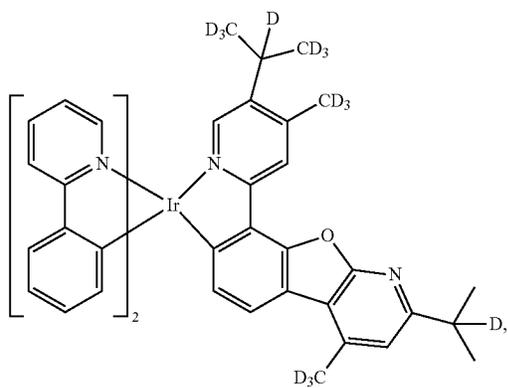
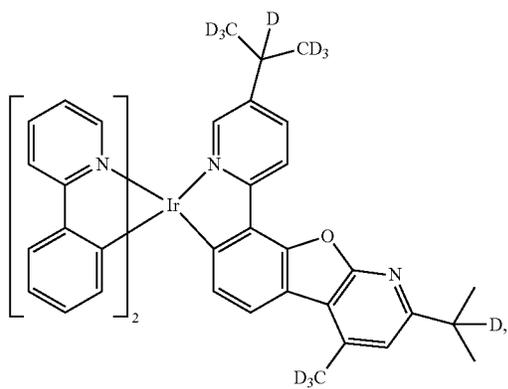
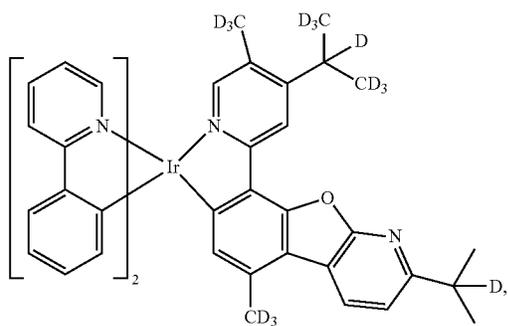
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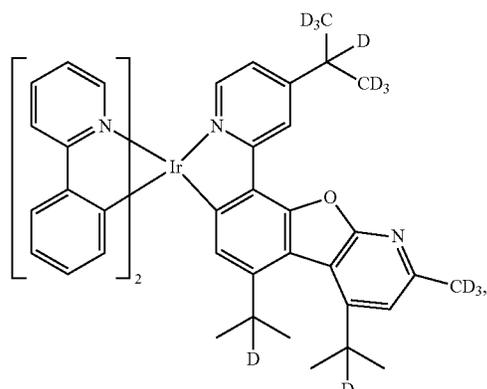
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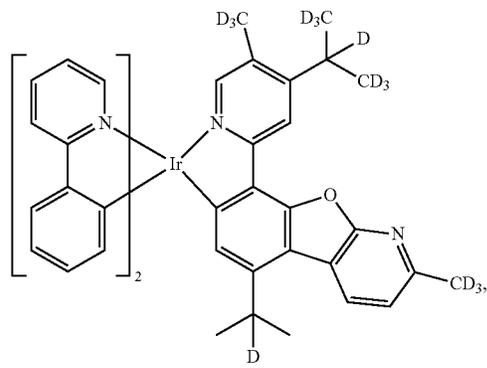
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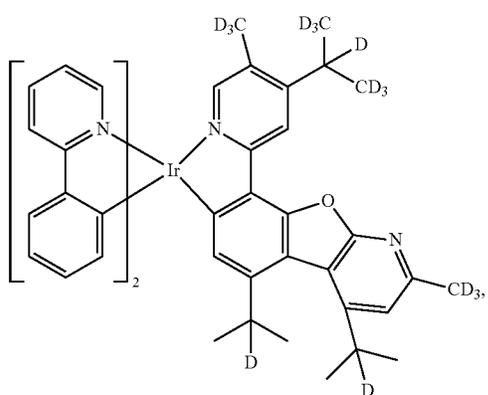
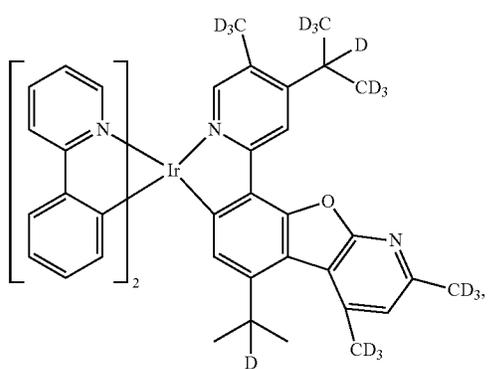
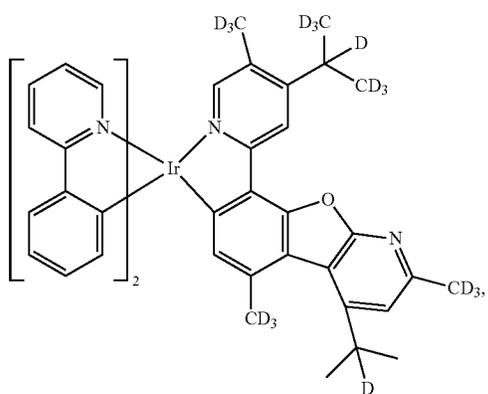
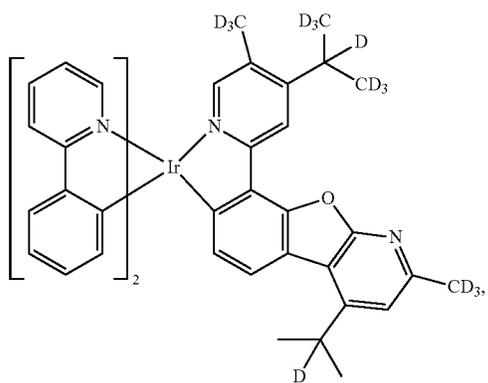
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D73

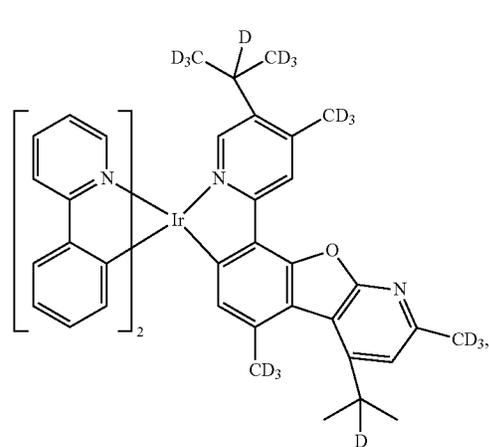
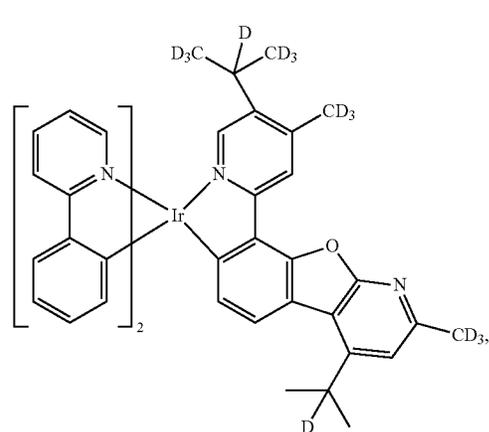
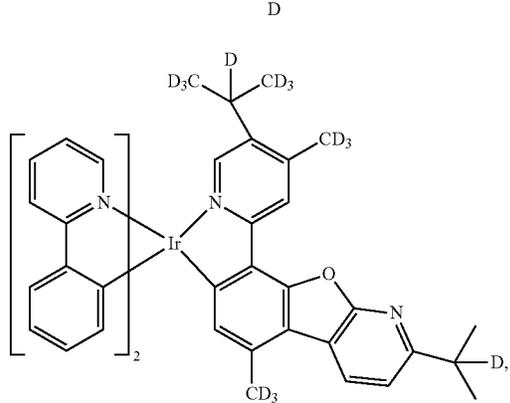
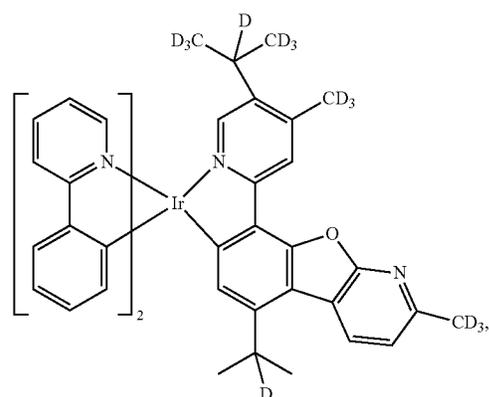
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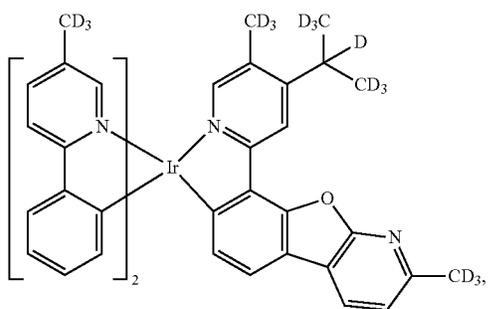
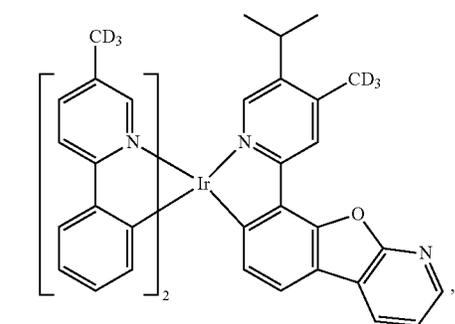
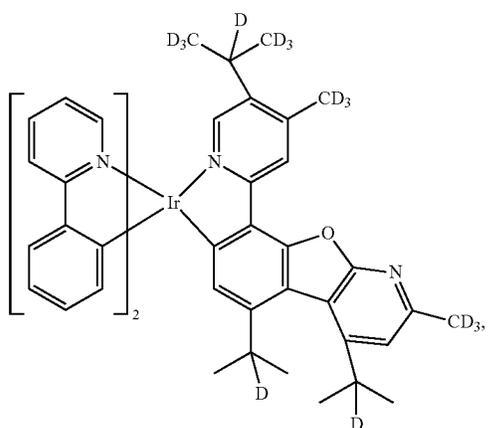
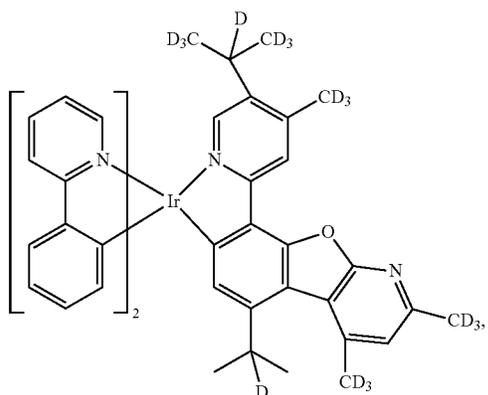
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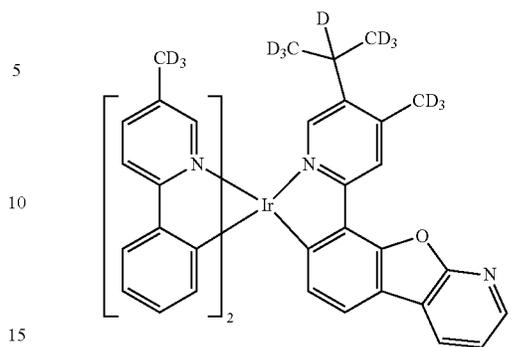
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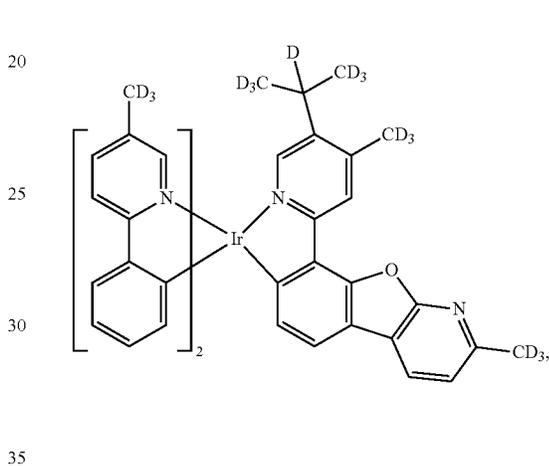
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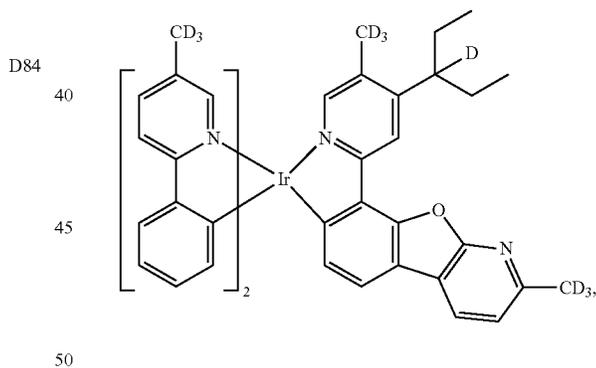
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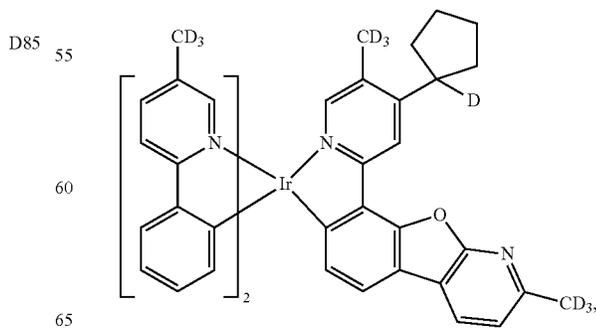
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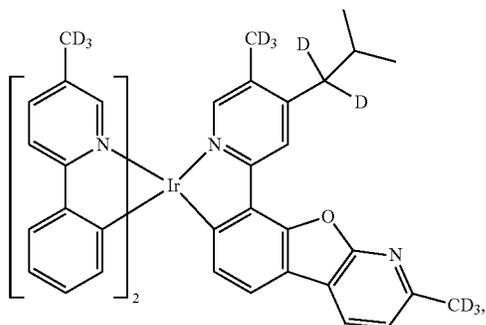
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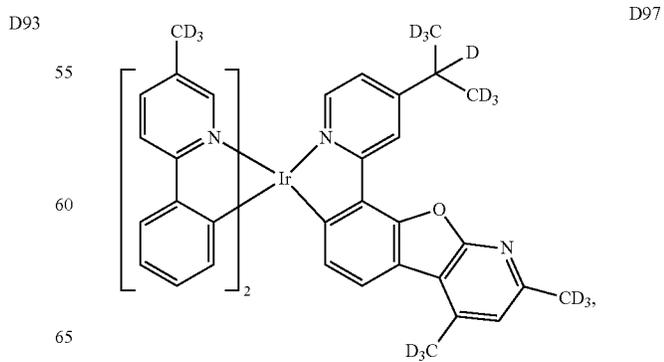
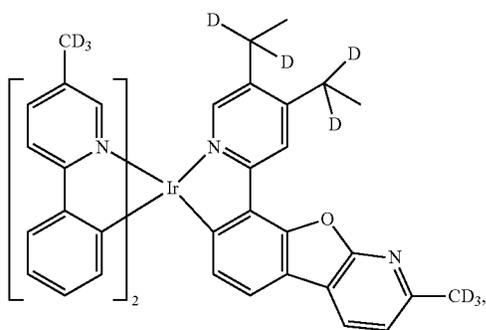
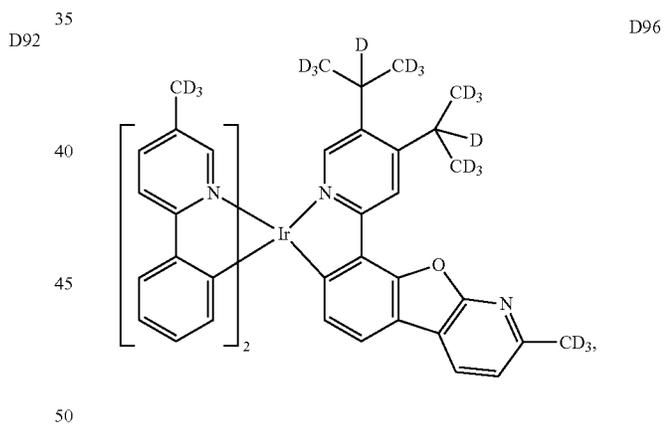
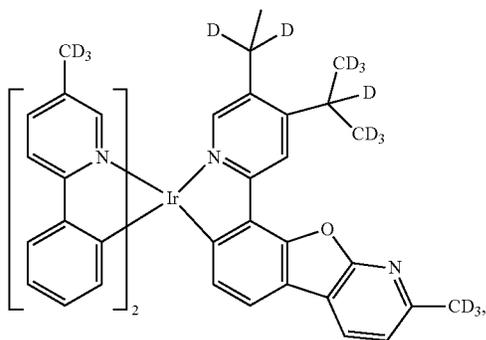
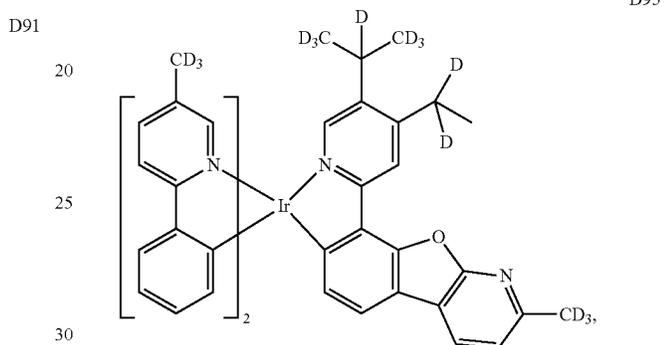
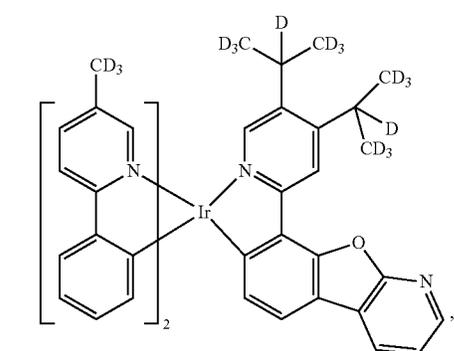
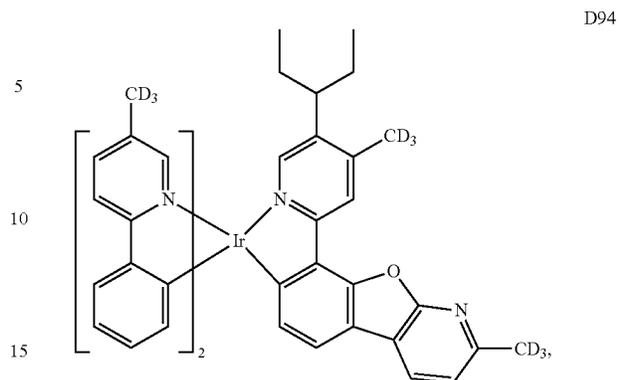
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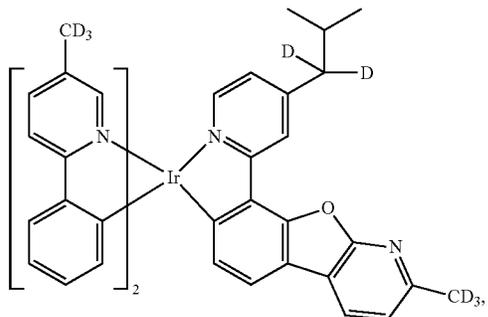


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**363**

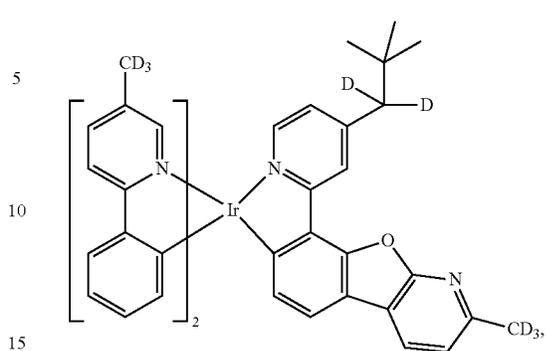
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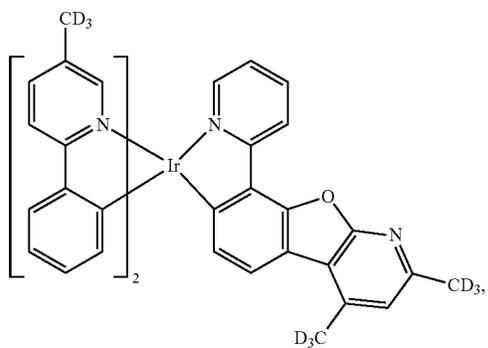
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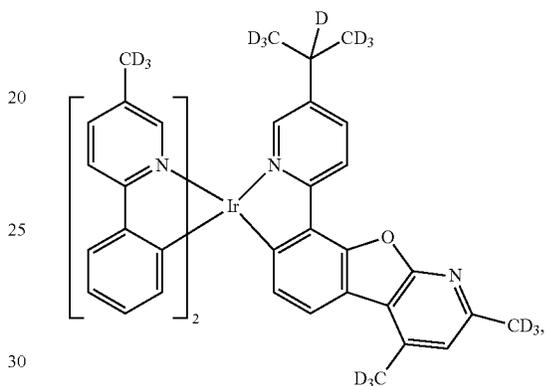
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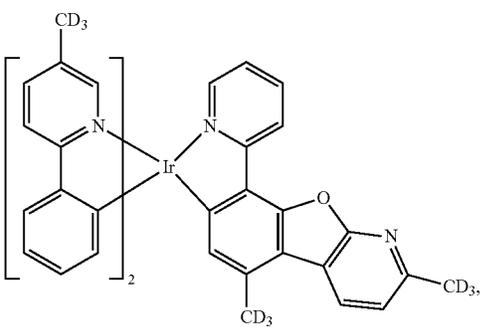
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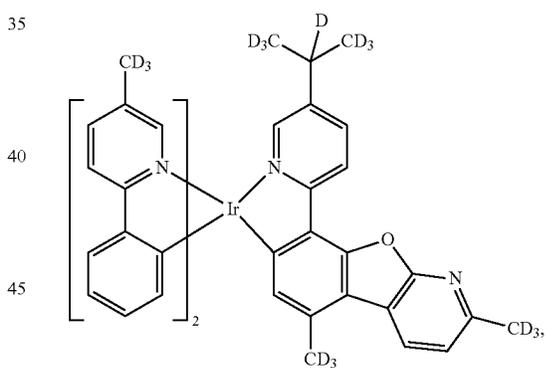
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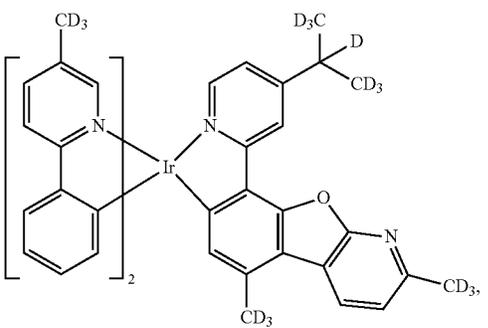
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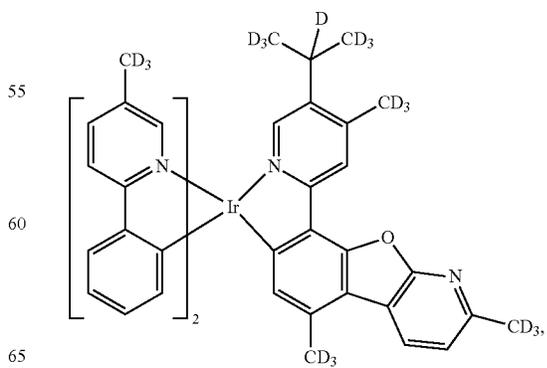
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D104



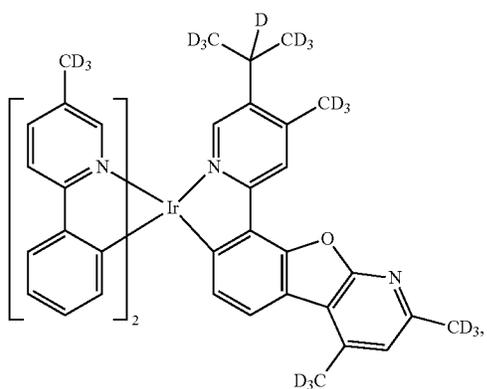
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D105

**365**

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D106

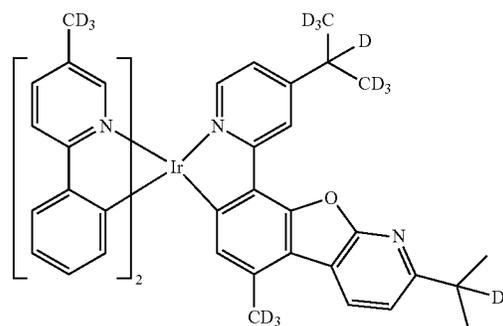
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**366**

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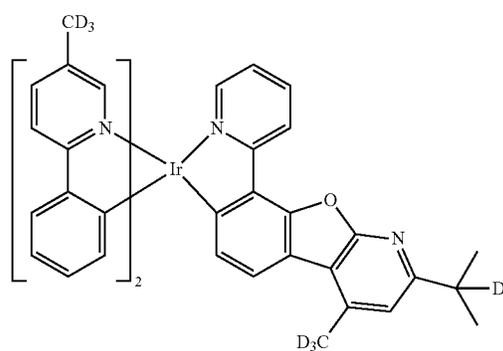
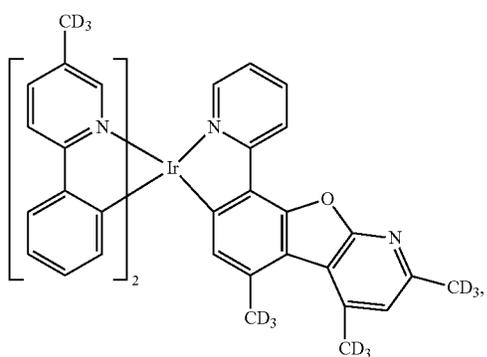
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D107

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D111

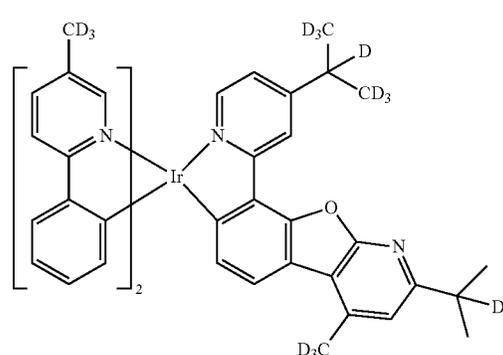
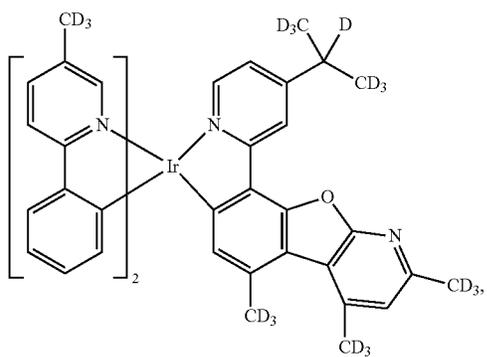
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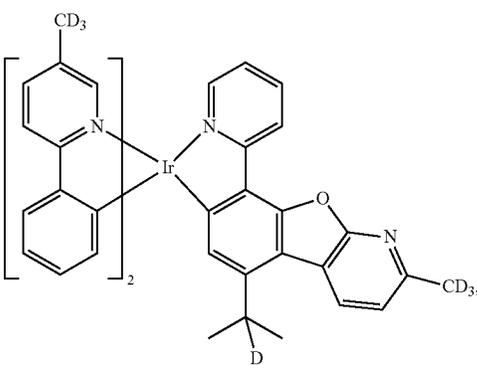
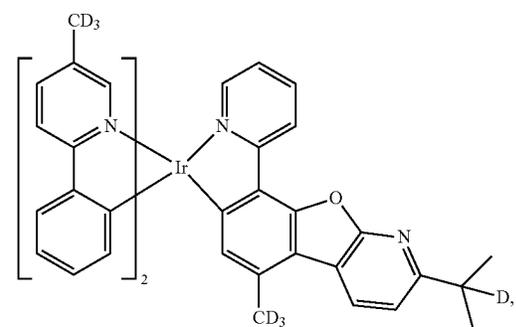
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D109

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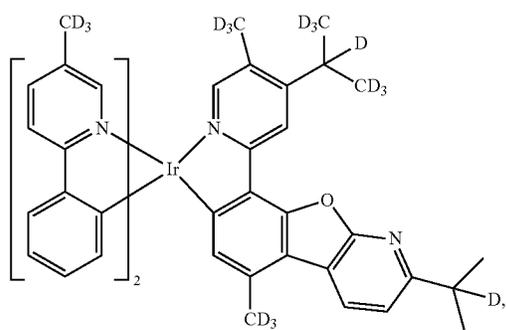
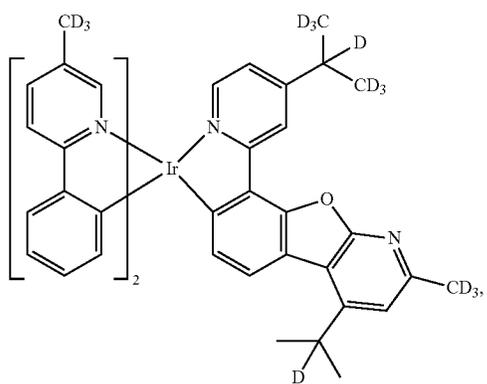
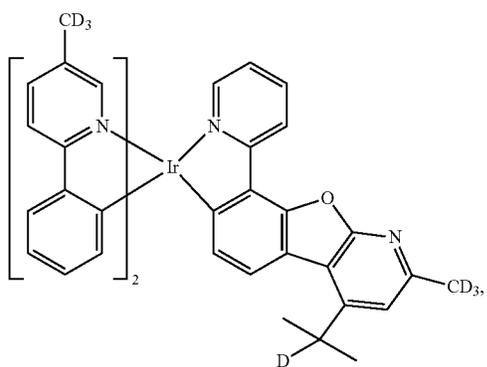
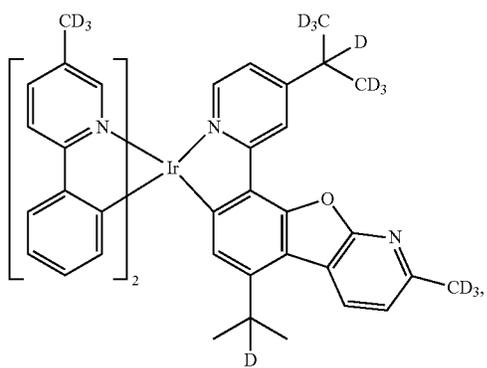
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D113

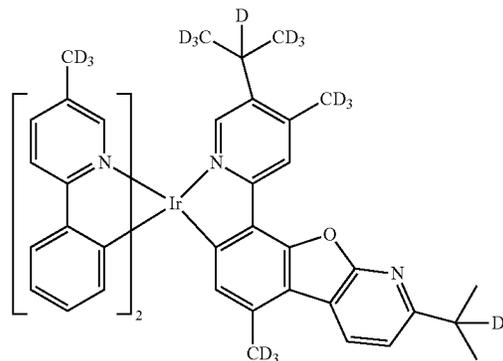
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**368**  
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D114

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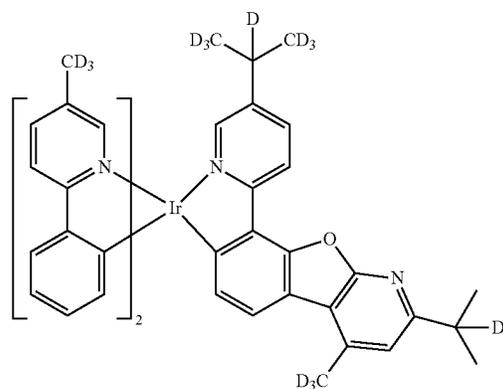


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D115

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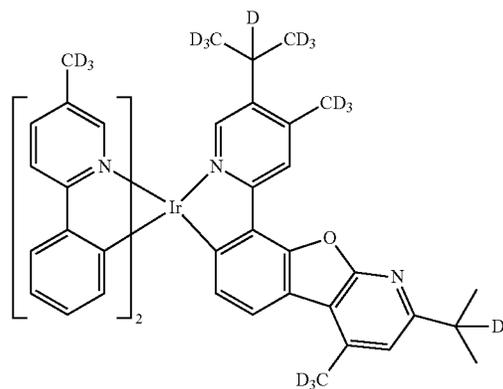


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D116

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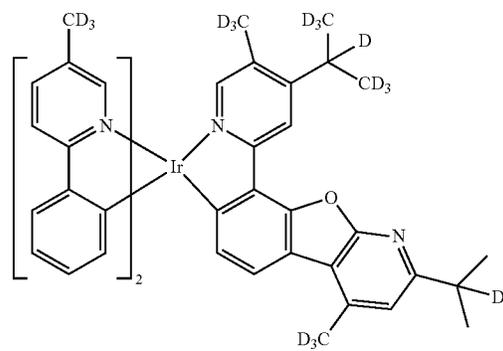
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D117

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D118

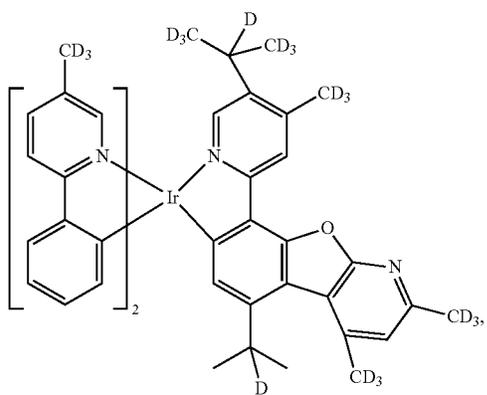
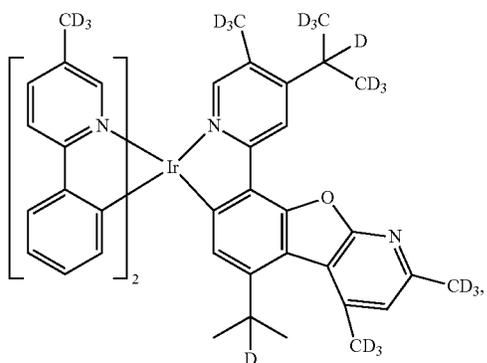
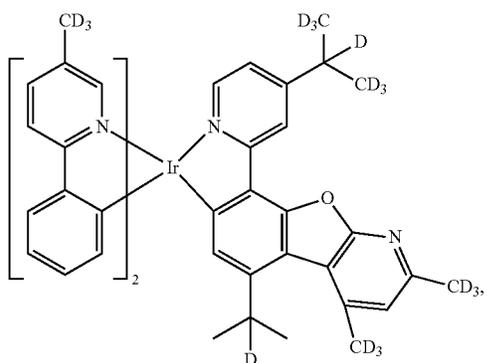
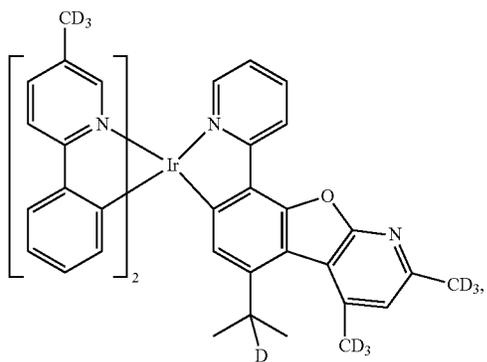
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D120

D121

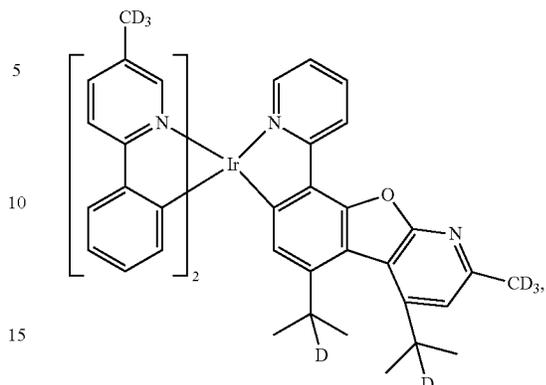


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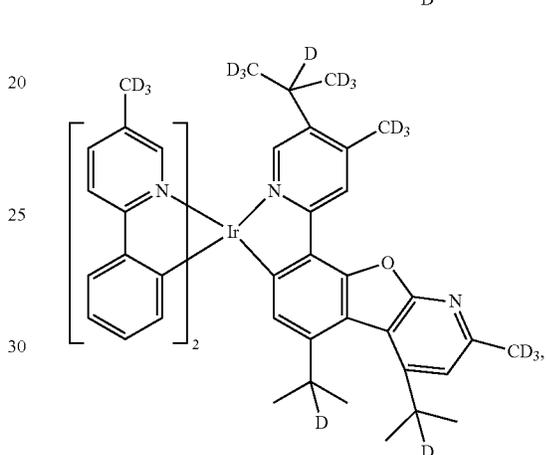
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D130



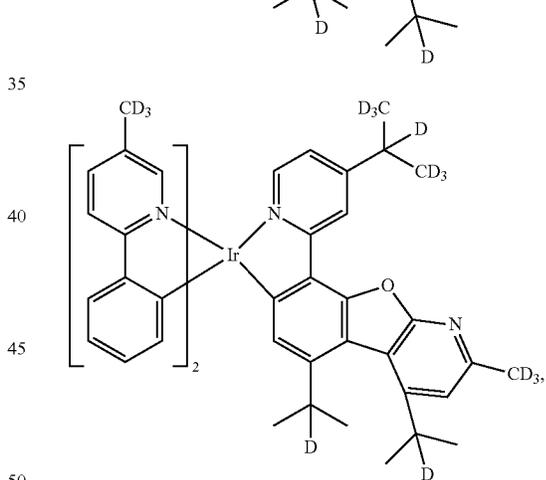
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D131



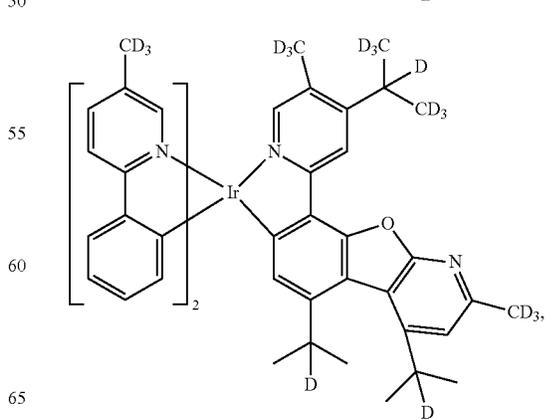
D135

D132



D136

D133



D137

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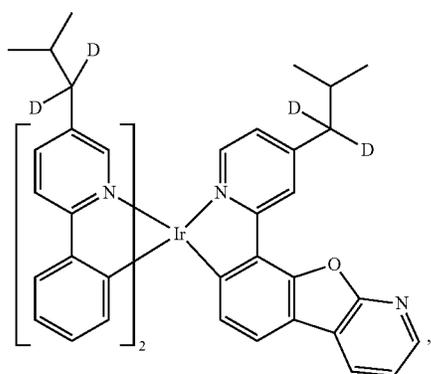
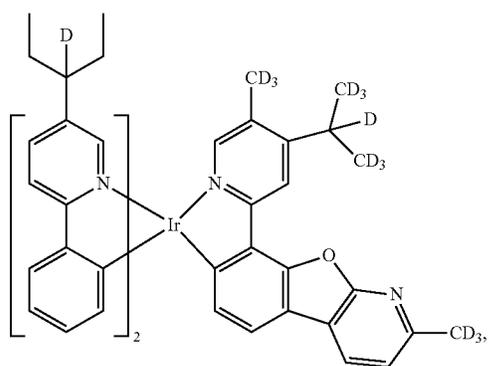
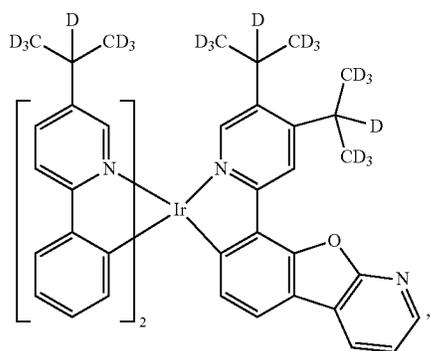
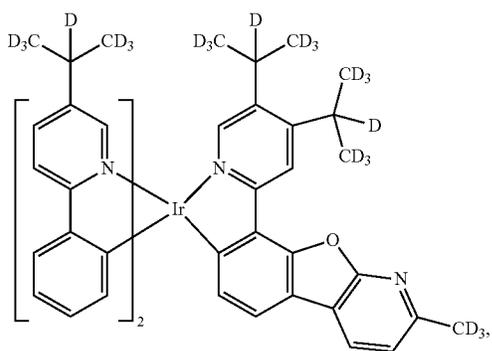
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**373**

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**374**

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D138

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D139

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D140

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D141

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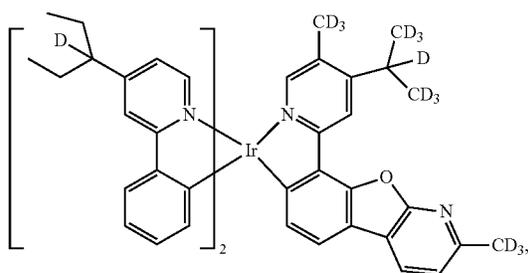
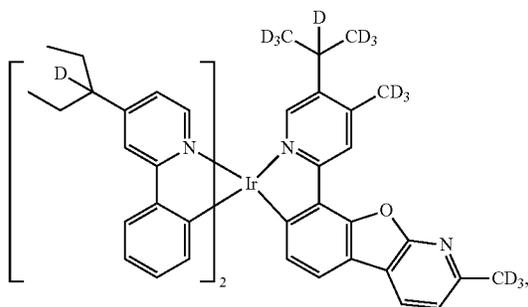
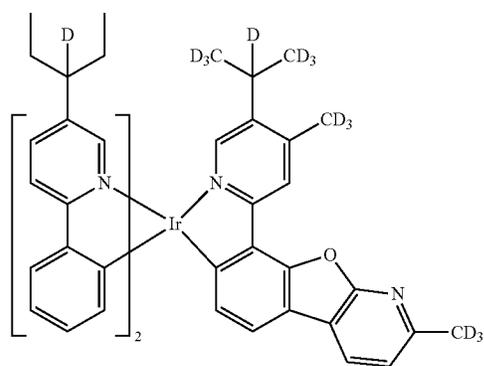
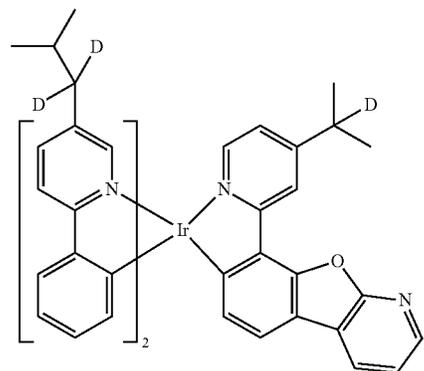
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D142

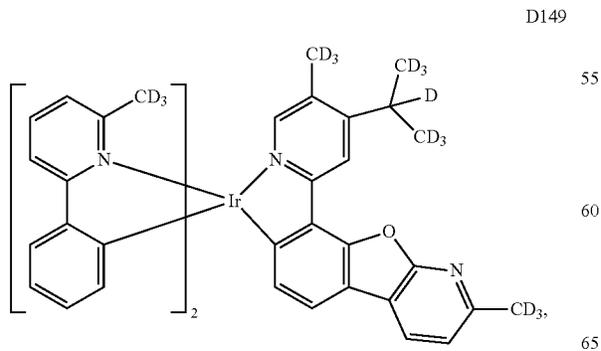
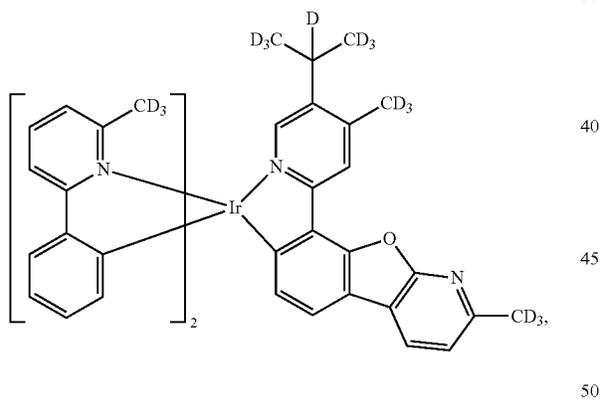
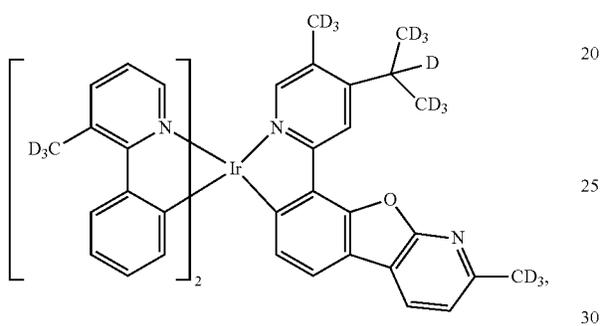
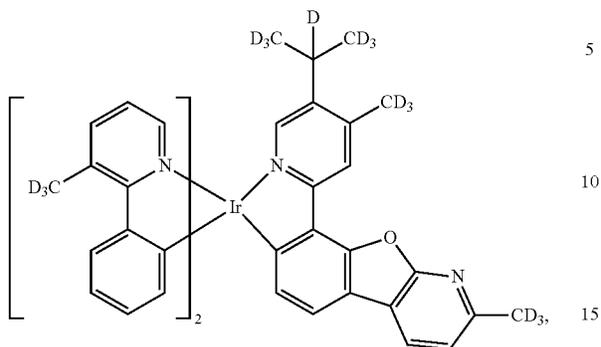
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D144

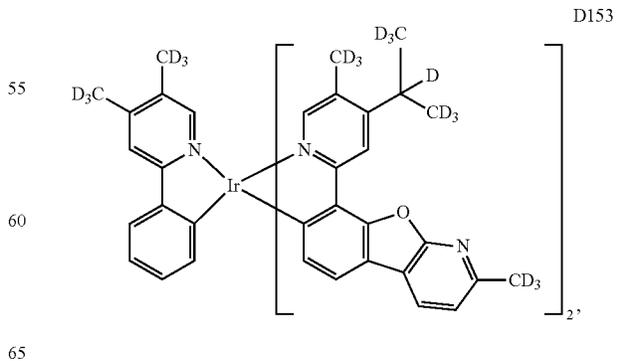
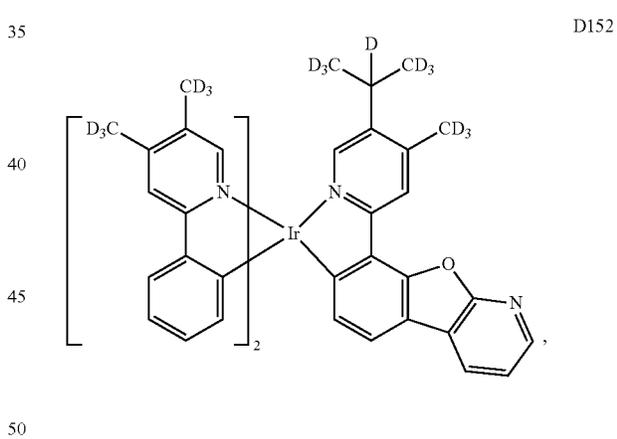
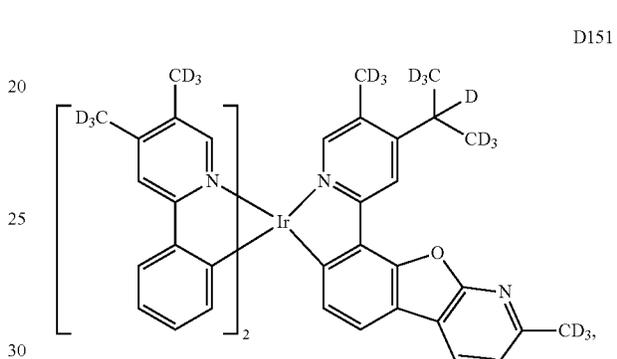
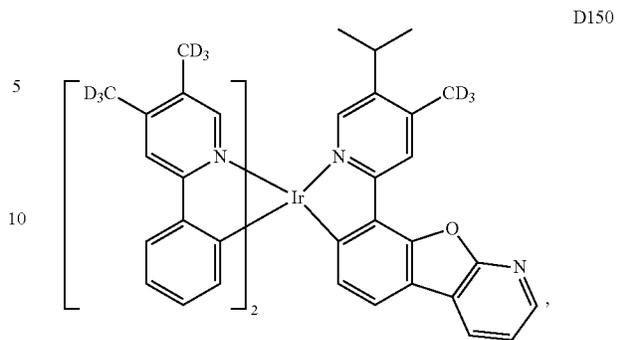
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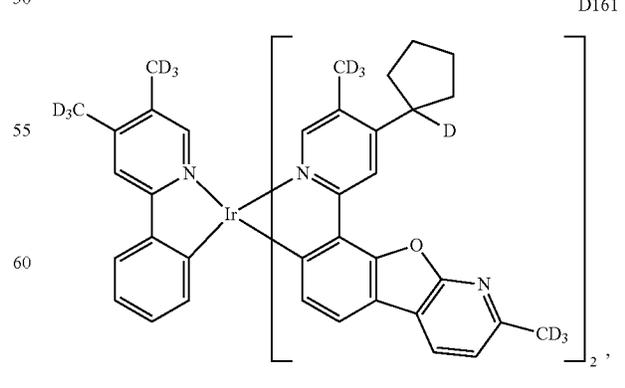
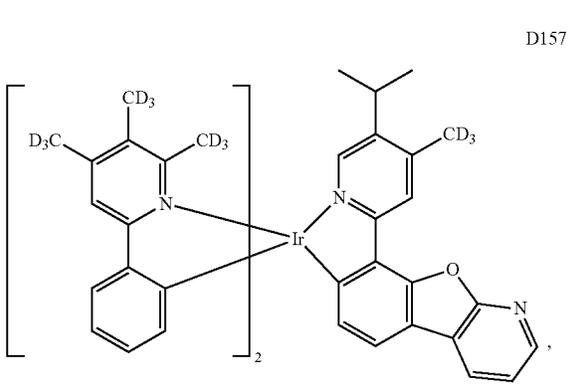
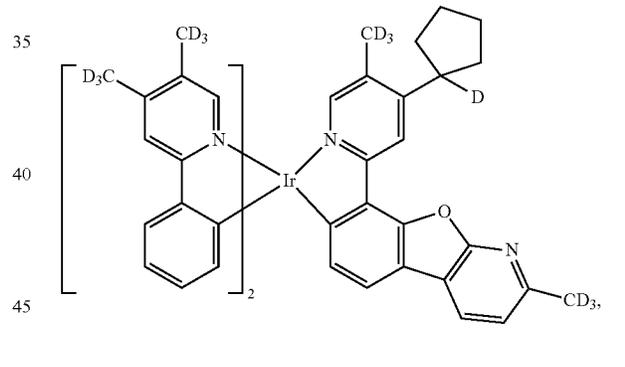
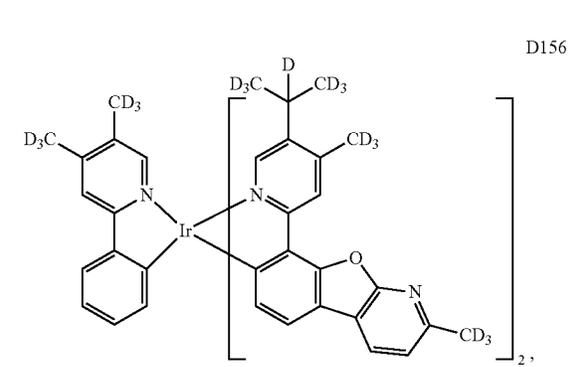
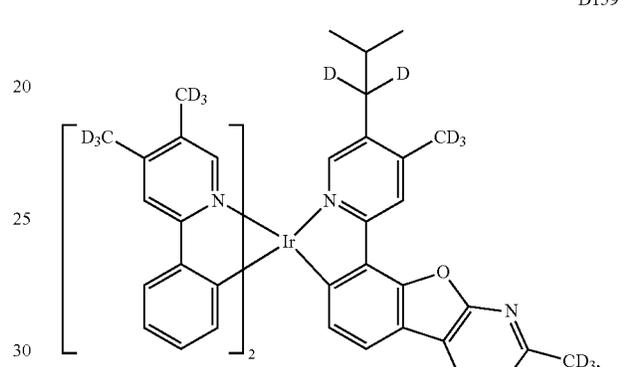
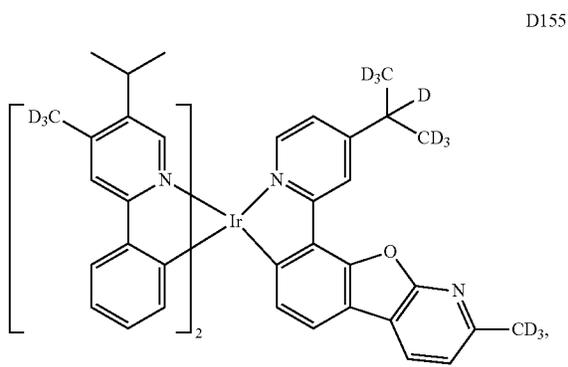
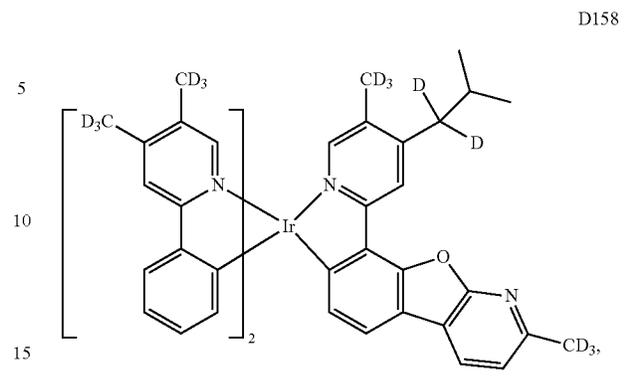
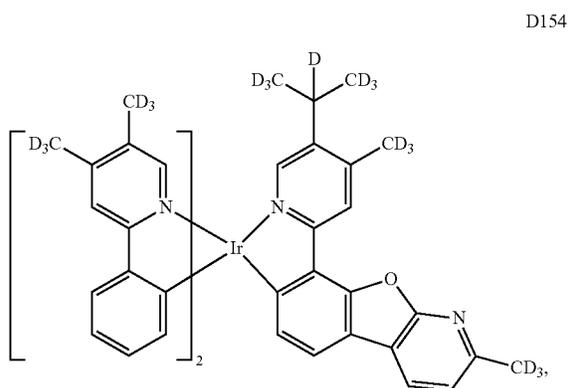


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**377**  
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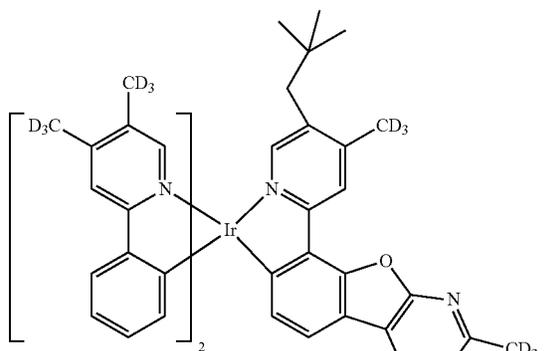
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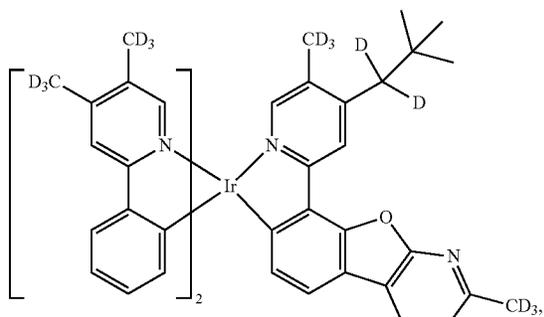
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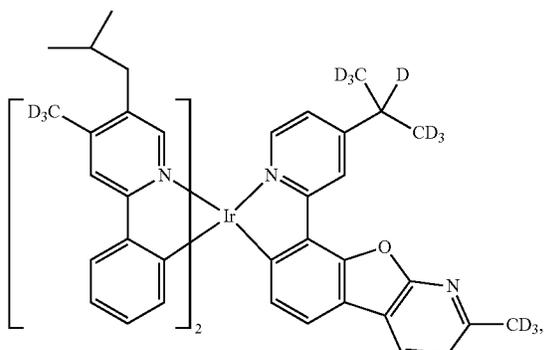
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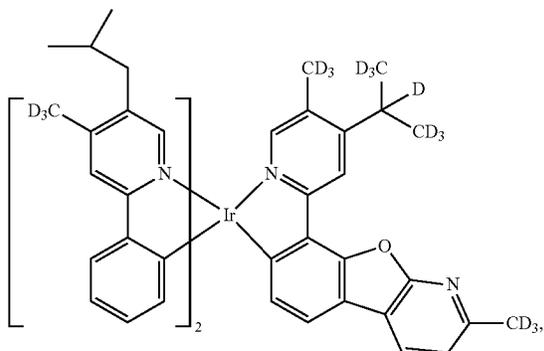
D163



D164



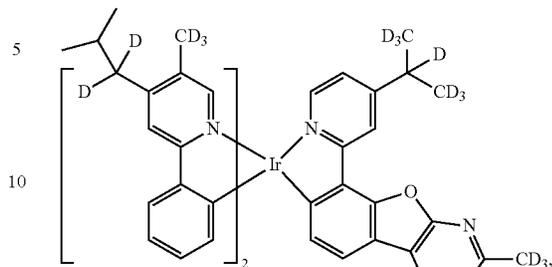
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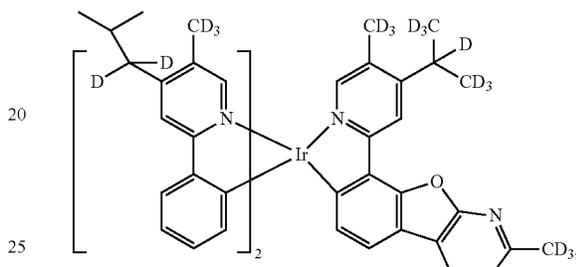
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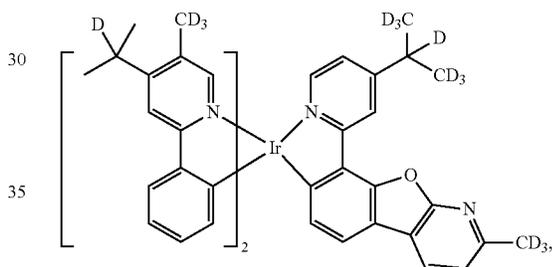
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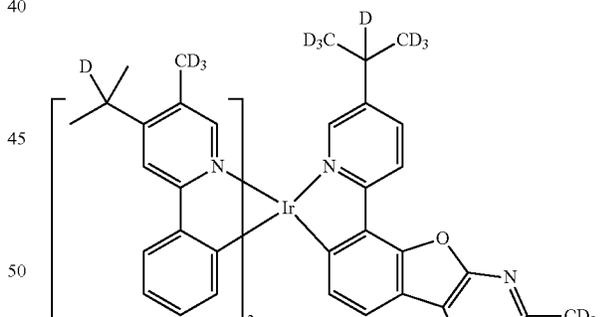
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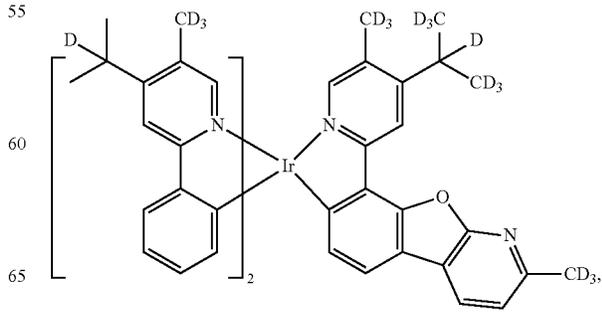
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D169



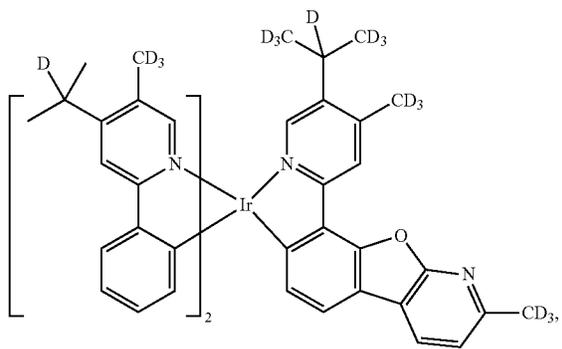
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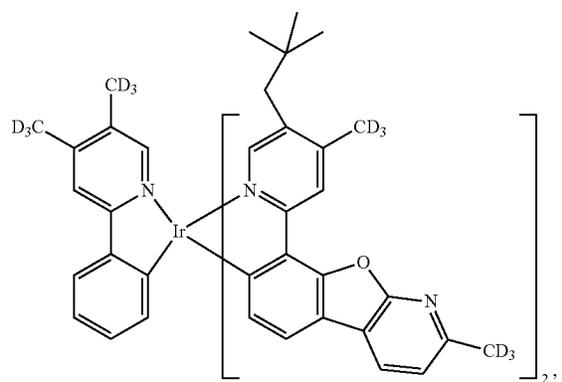
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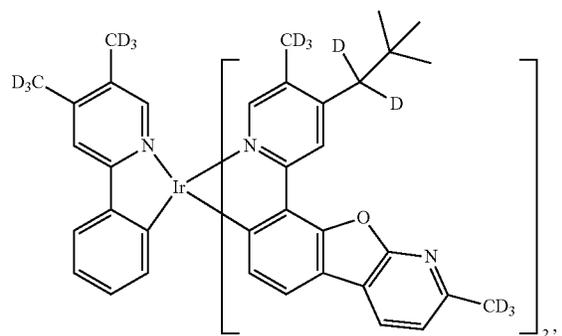
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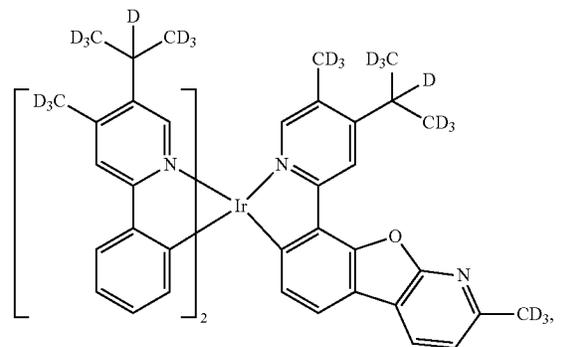
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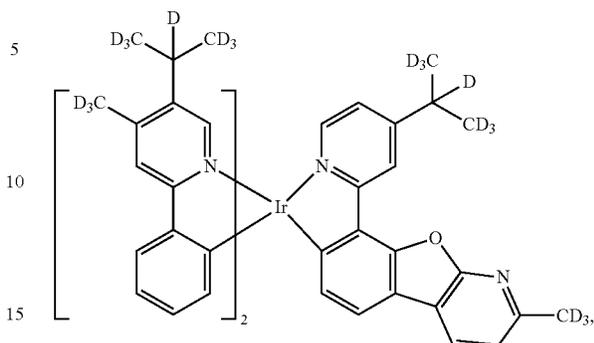
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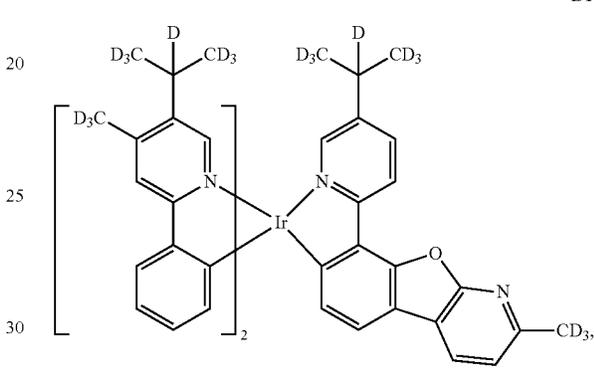
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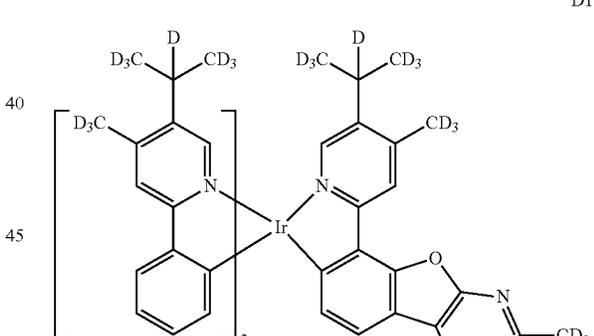
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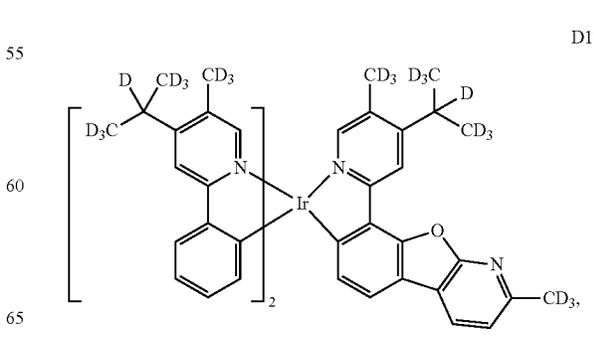
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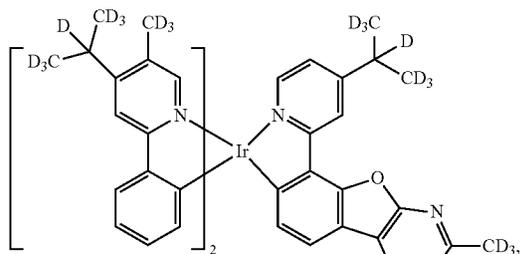
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D179



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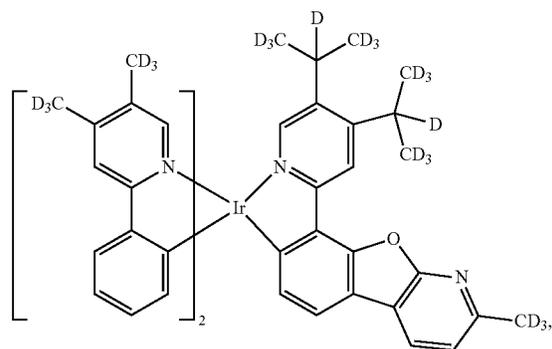
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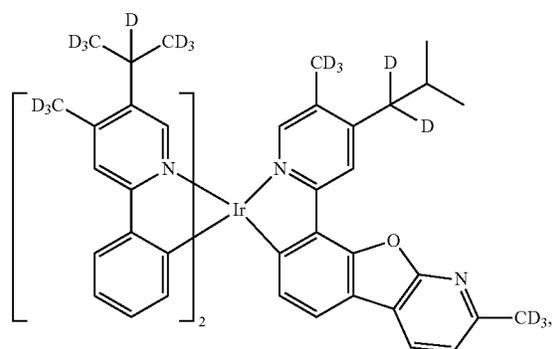
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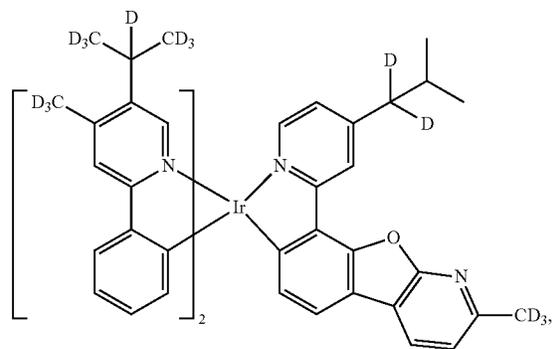
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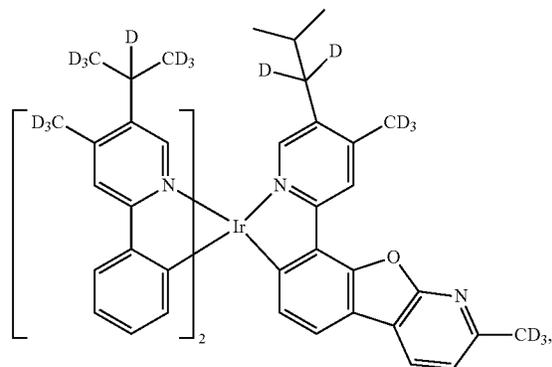
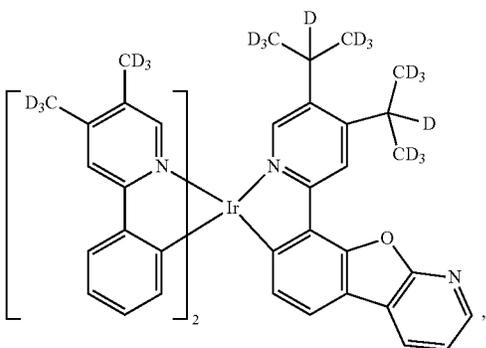
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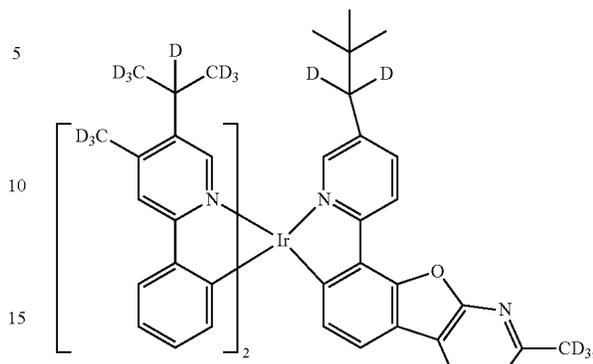
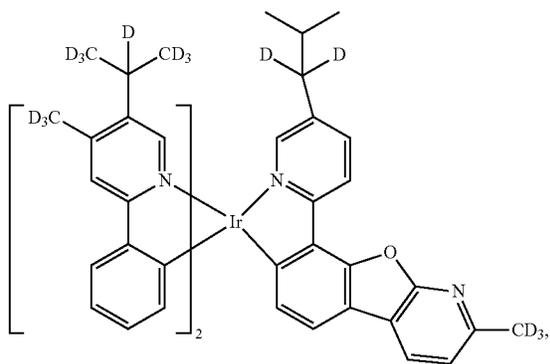


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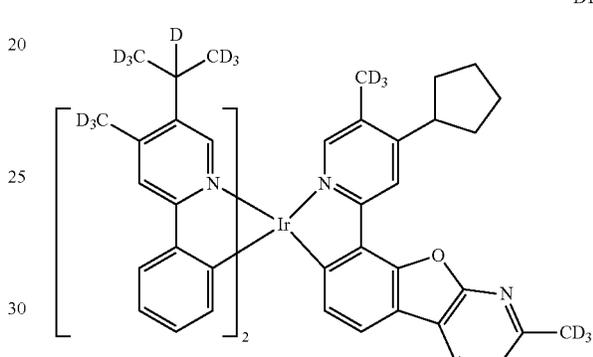
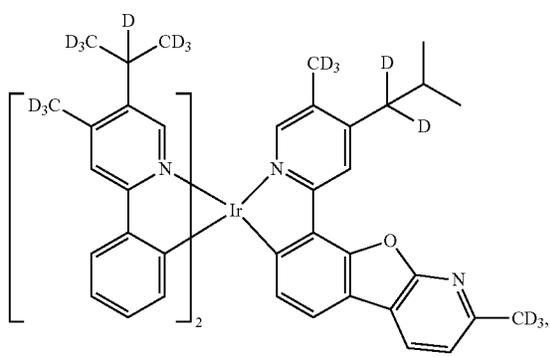
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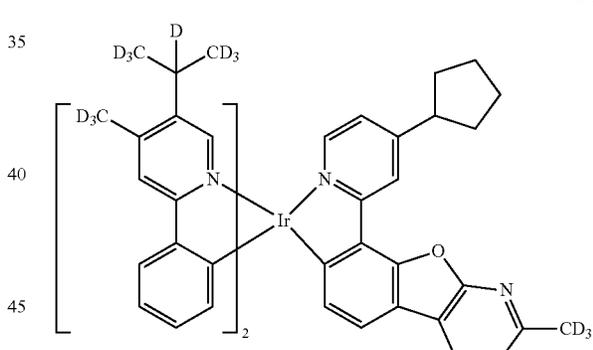
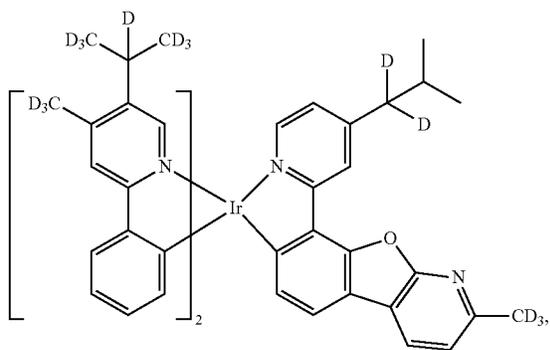
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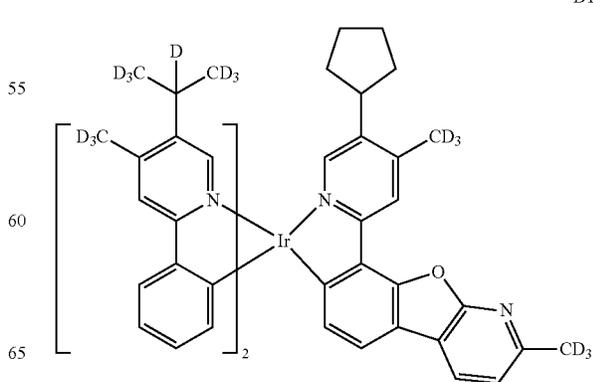
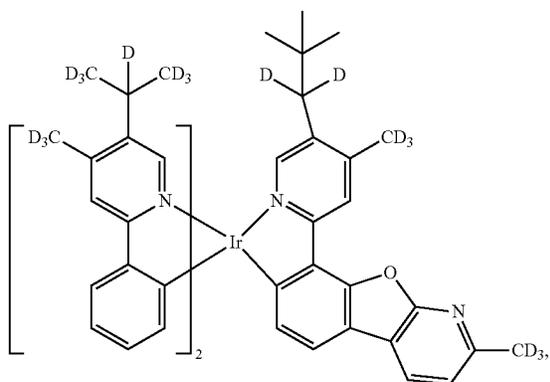
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D193



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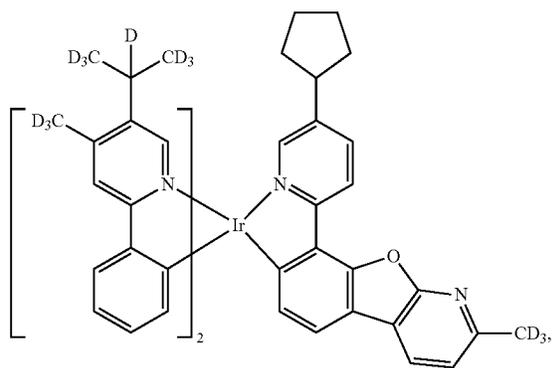
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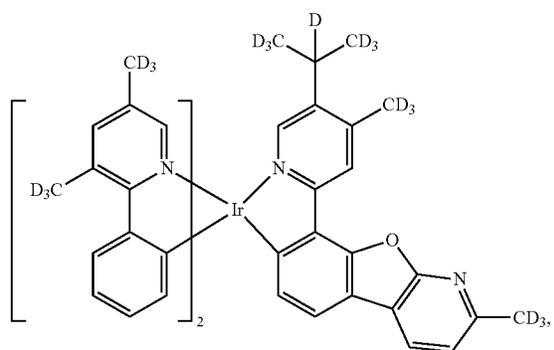
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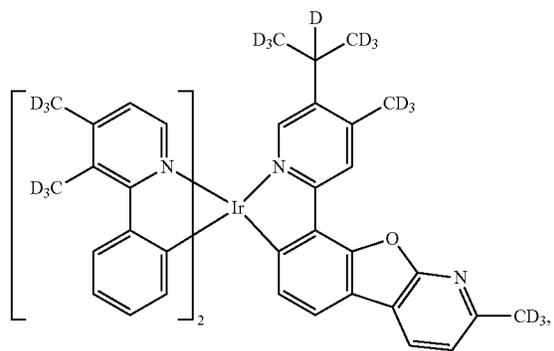
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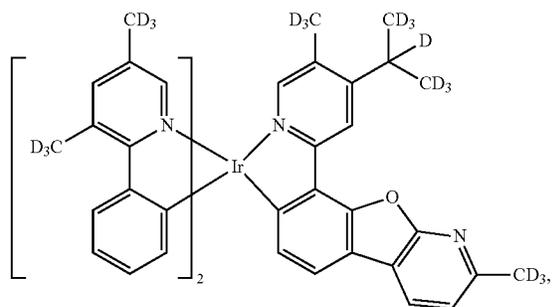
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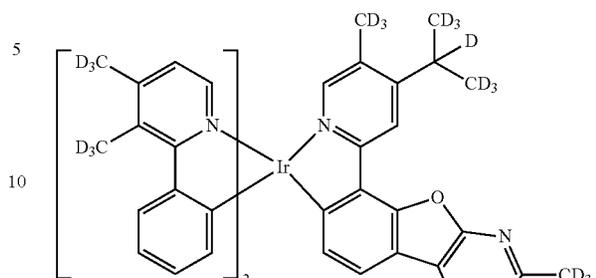
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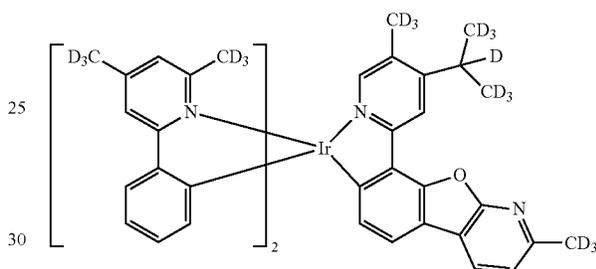
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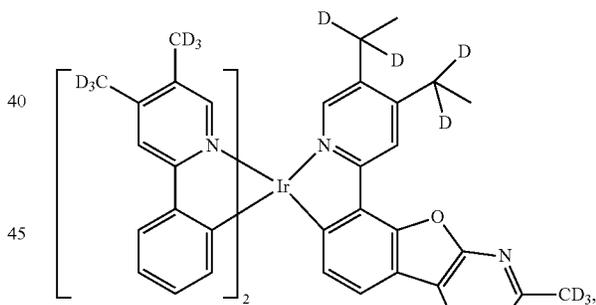
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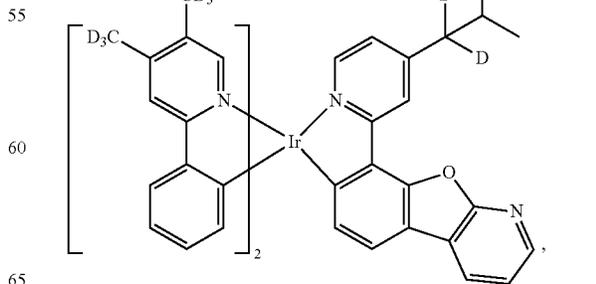
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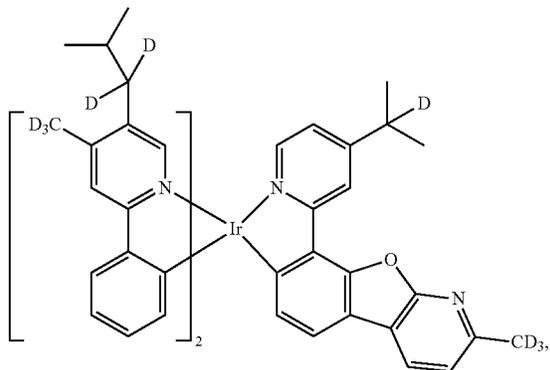
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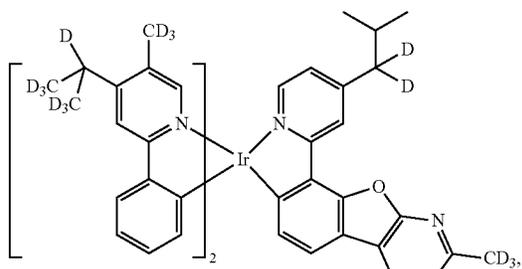
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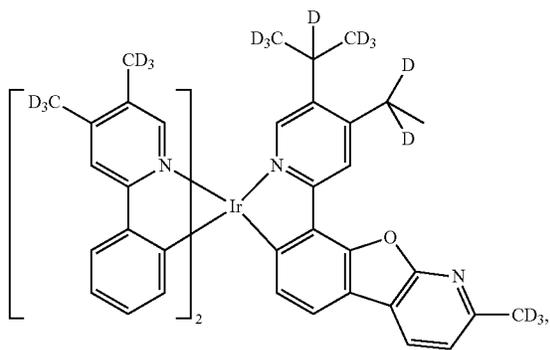
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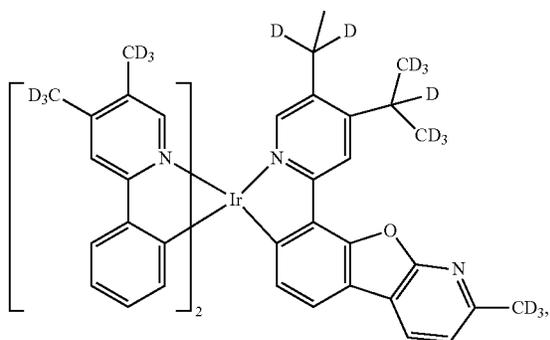
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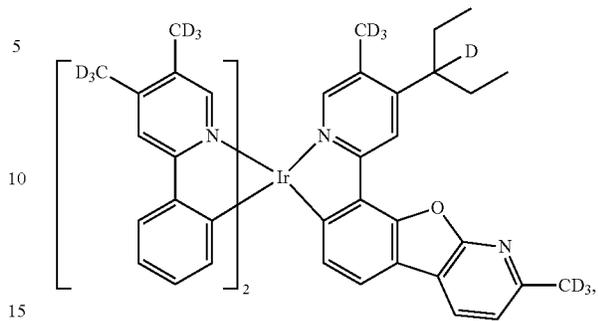
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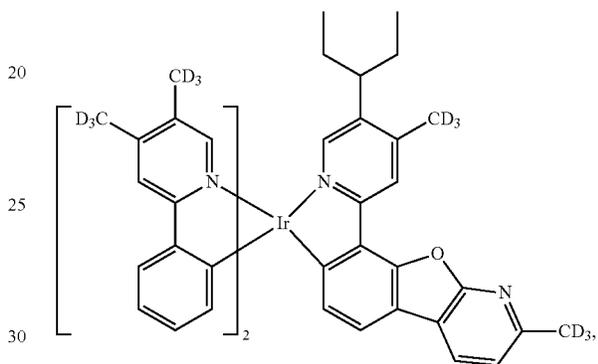
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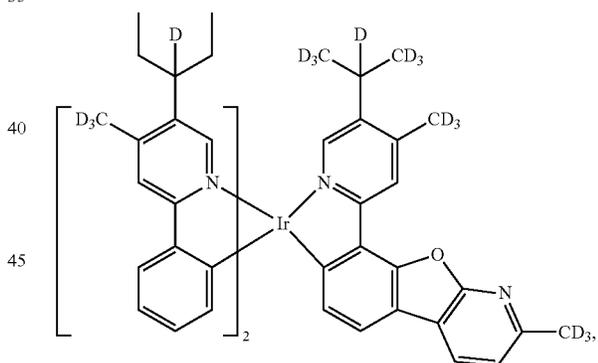
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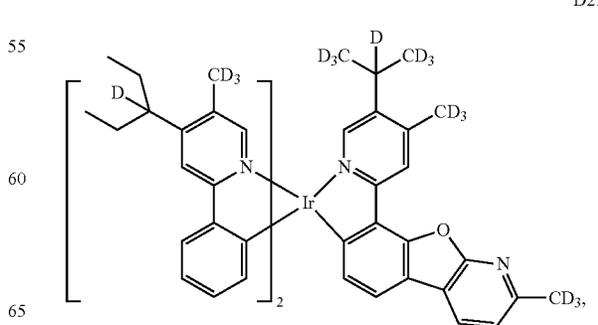
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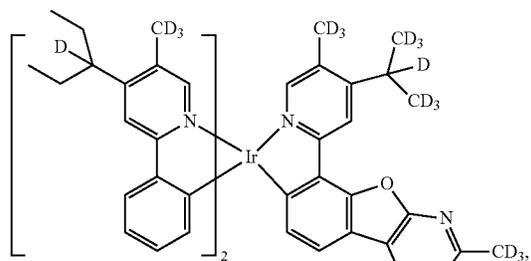
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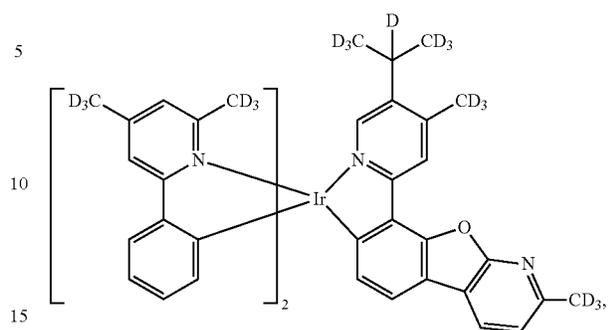
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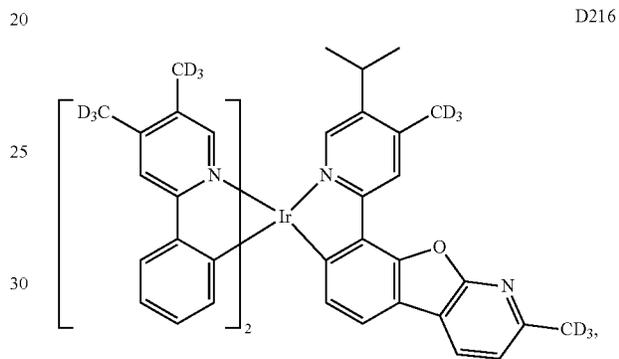
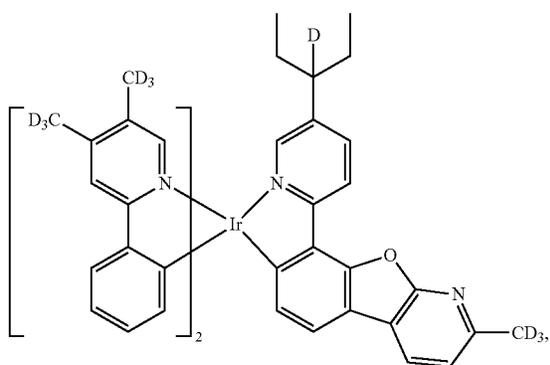
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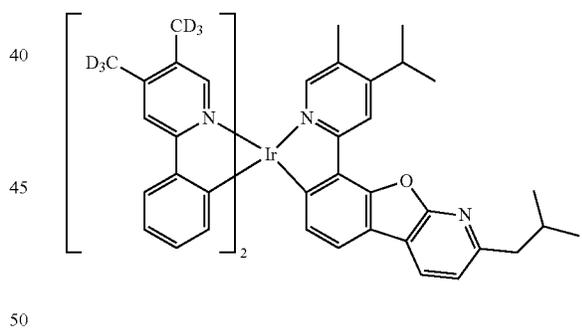
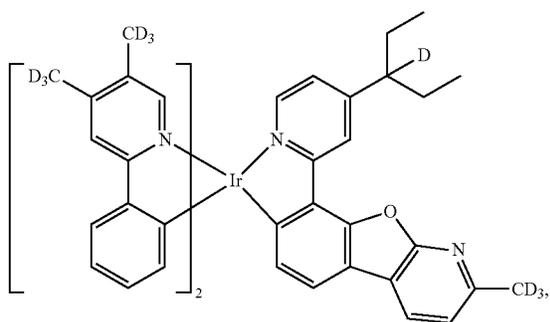


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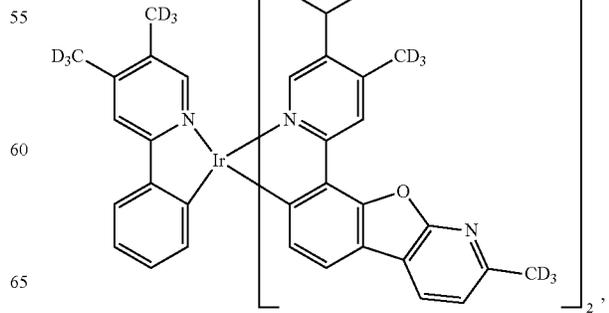
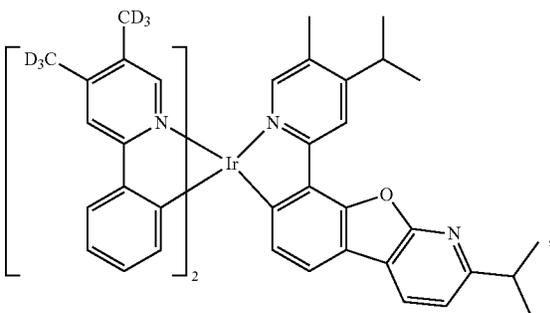
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D213



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D214



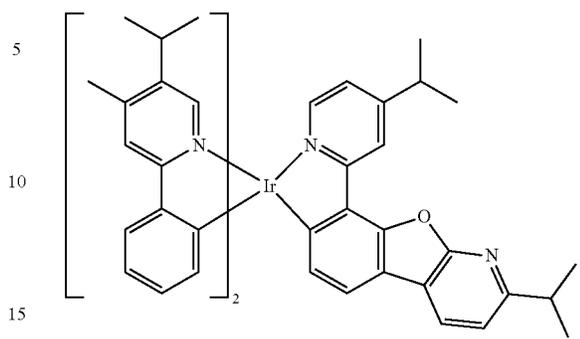
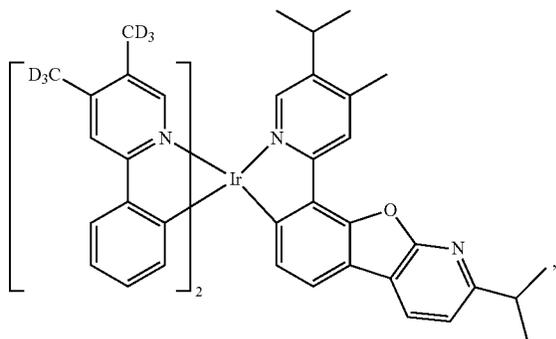
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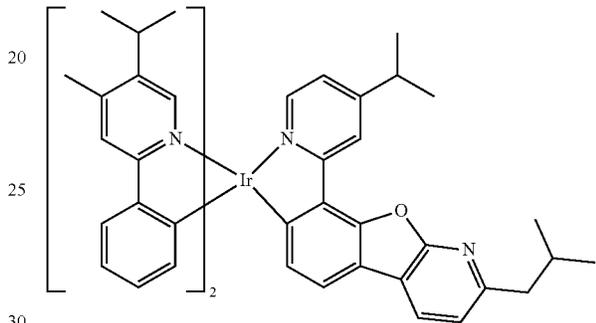
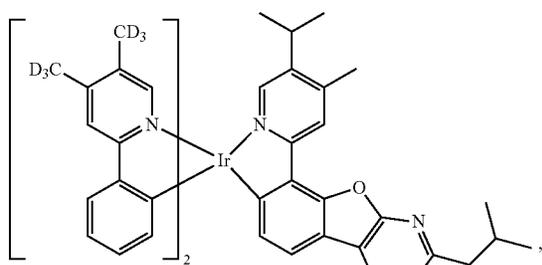
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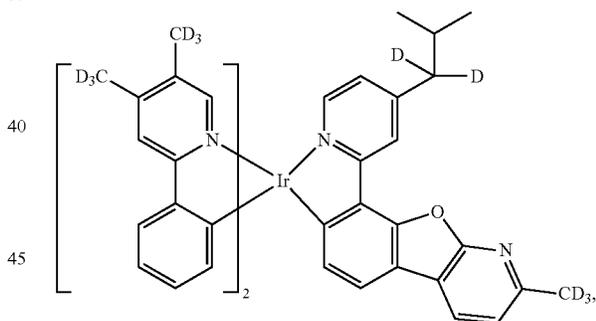
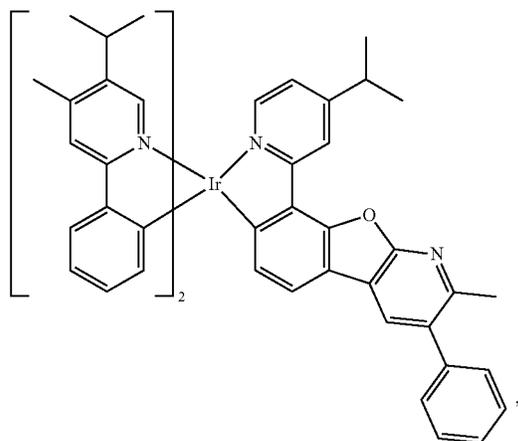
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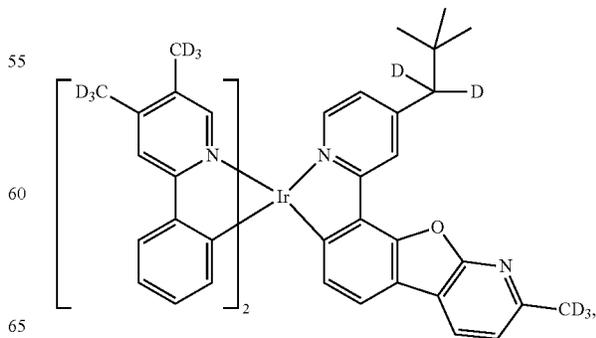
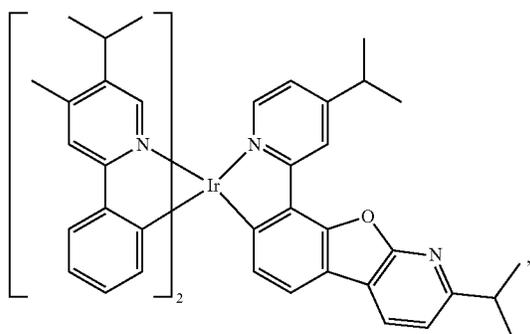
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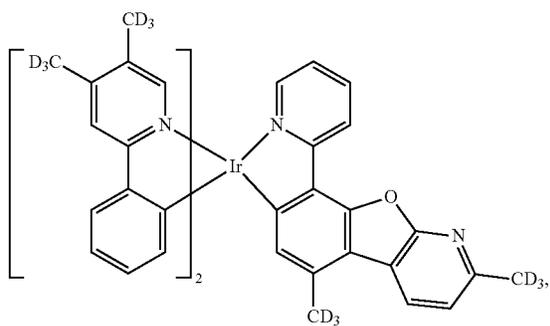
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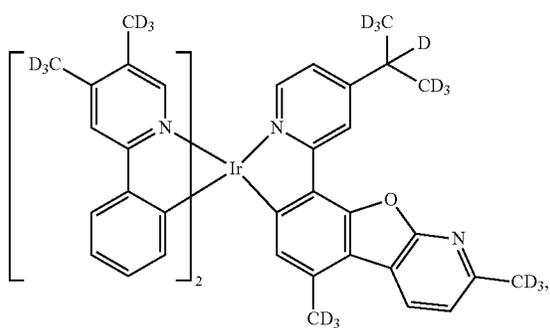
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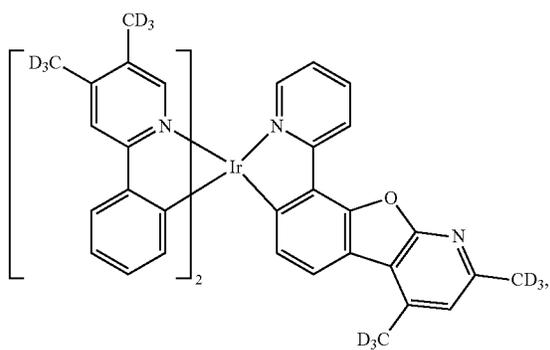
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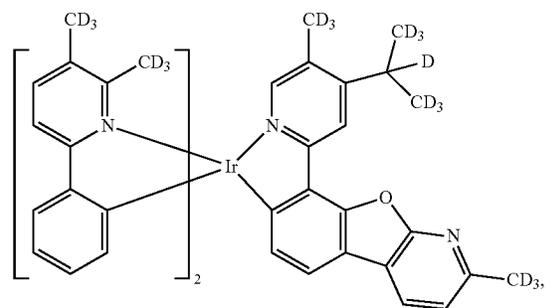
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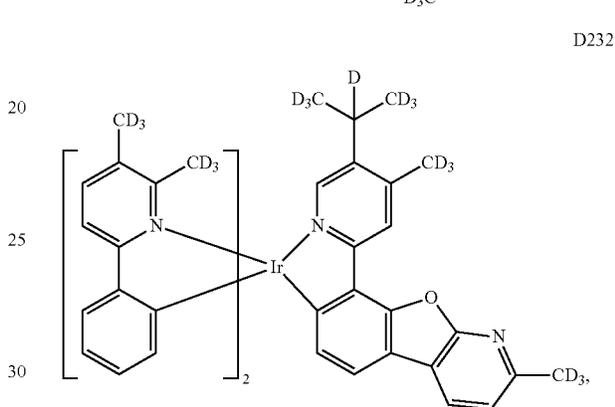
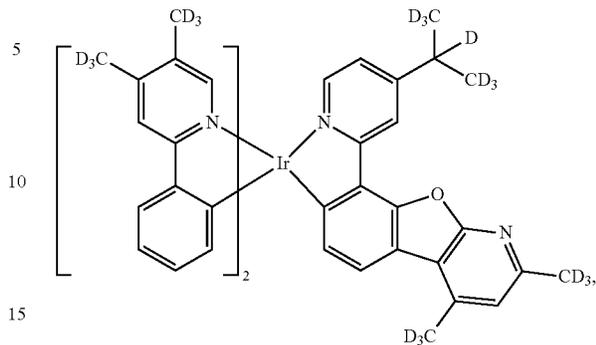
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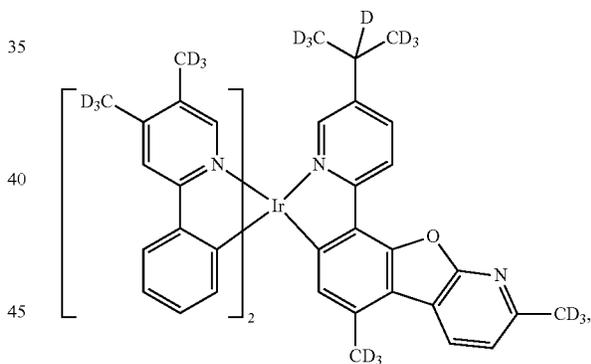
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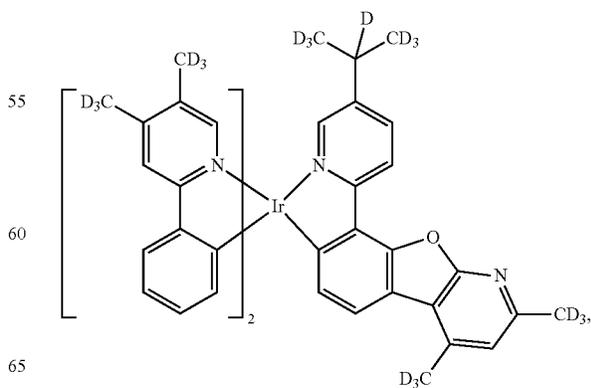
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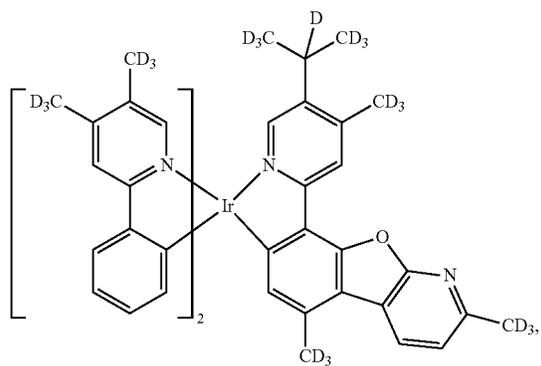
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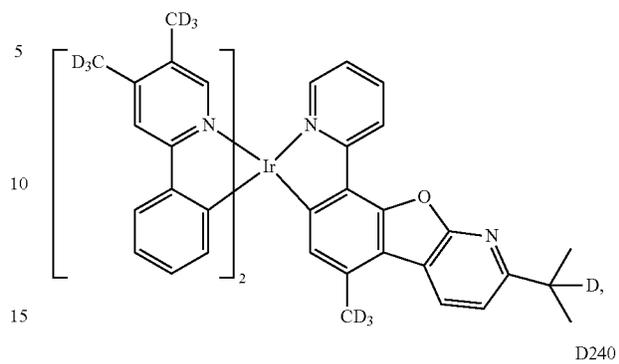
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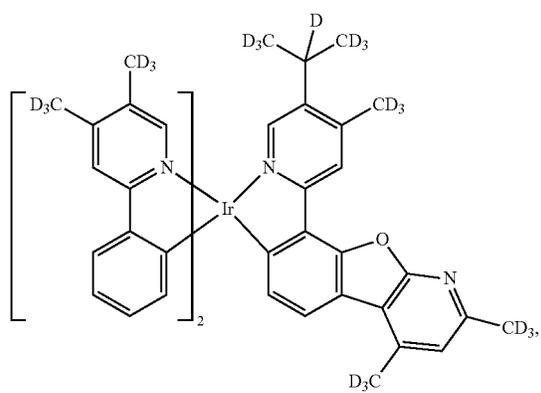
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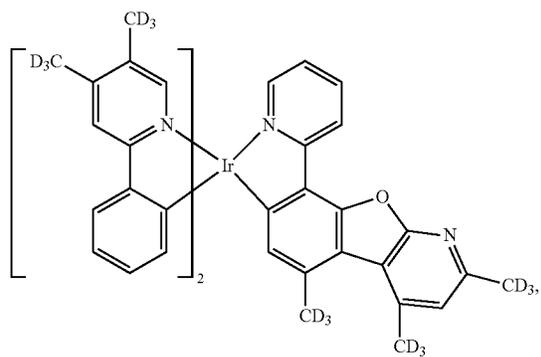
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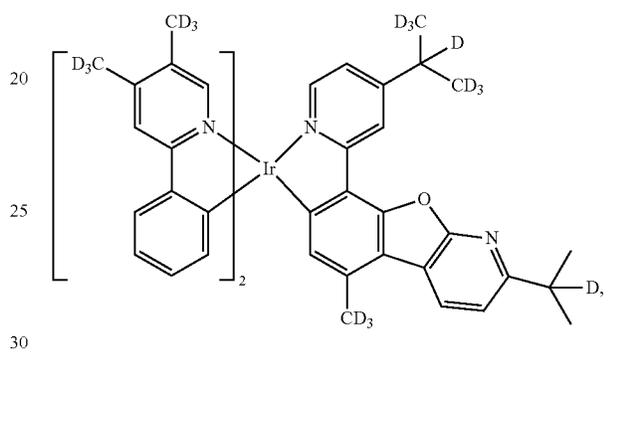
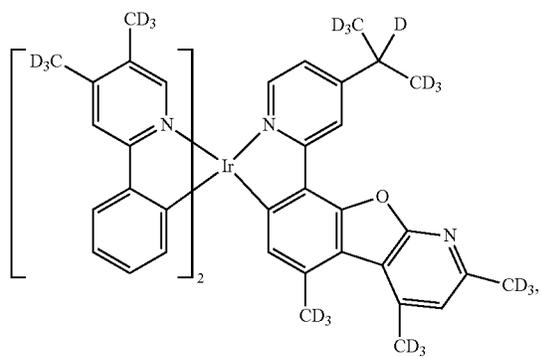
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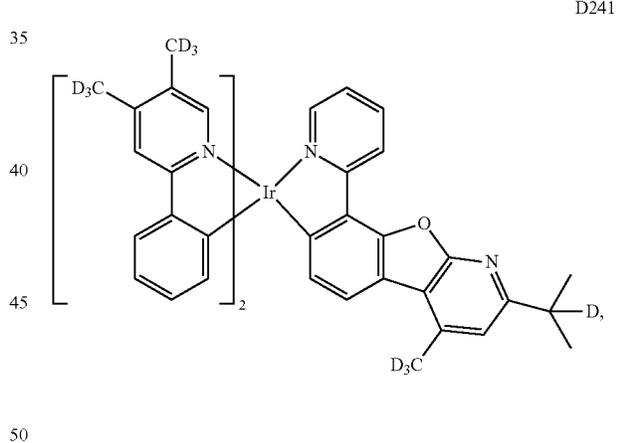


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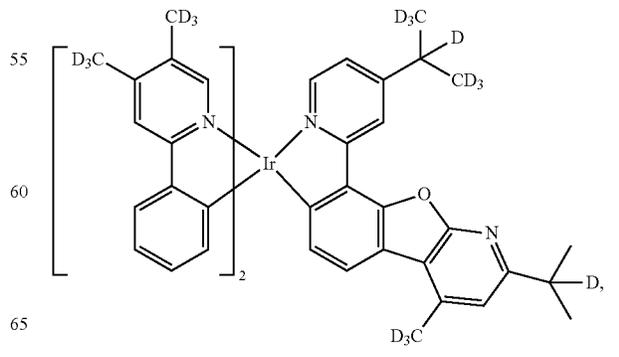


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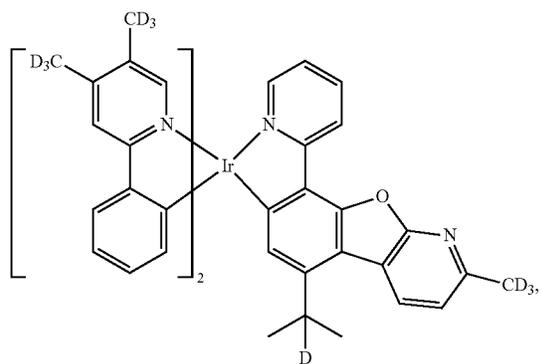


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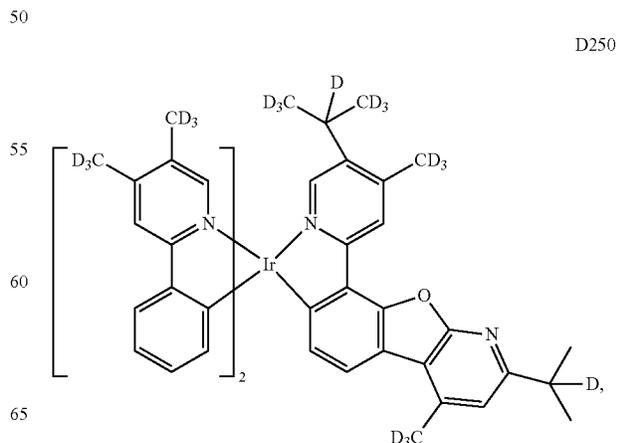
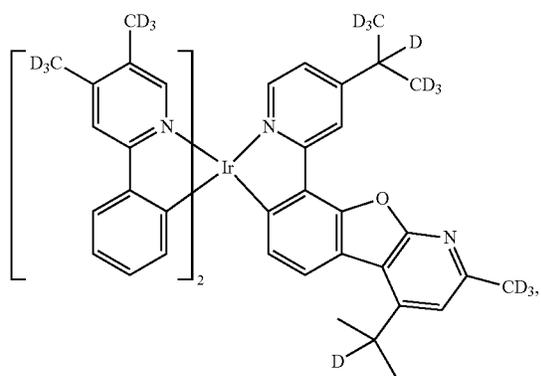
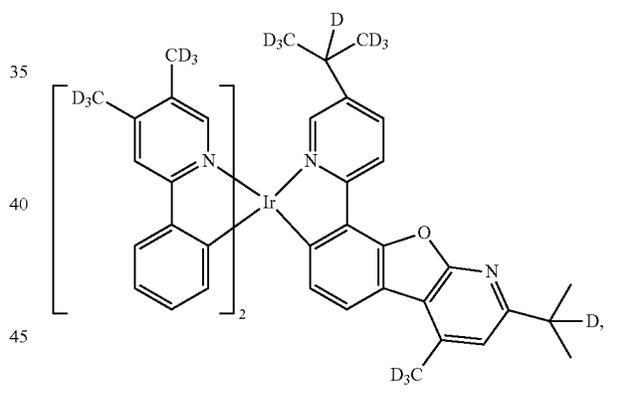
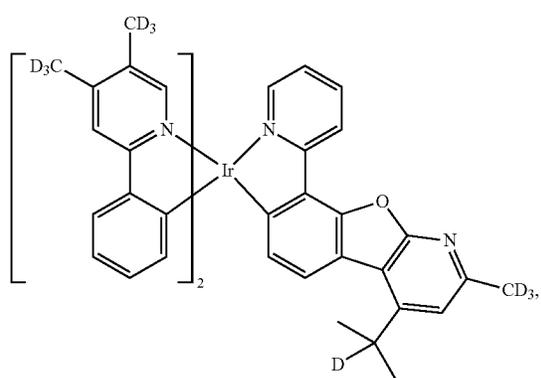
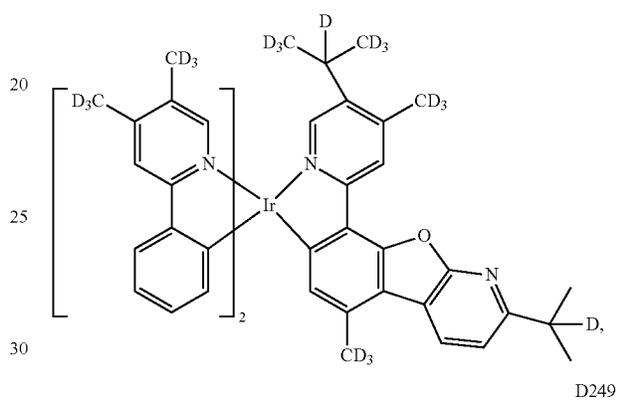
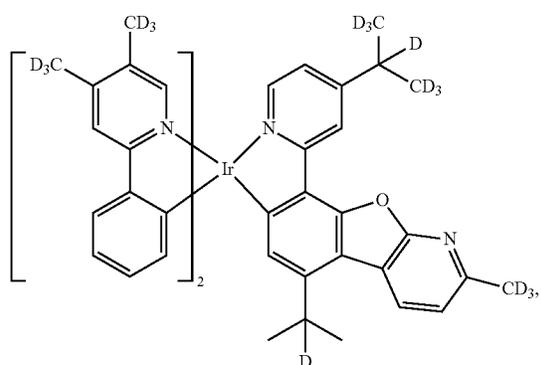
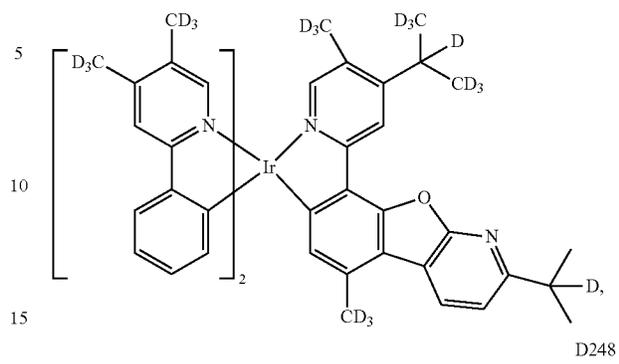
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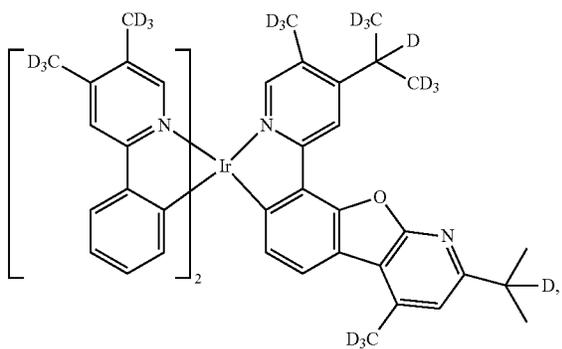
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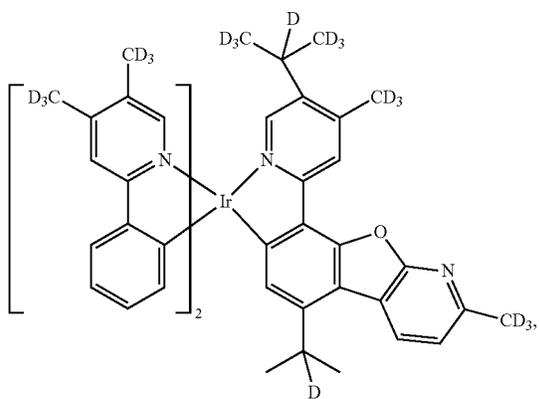
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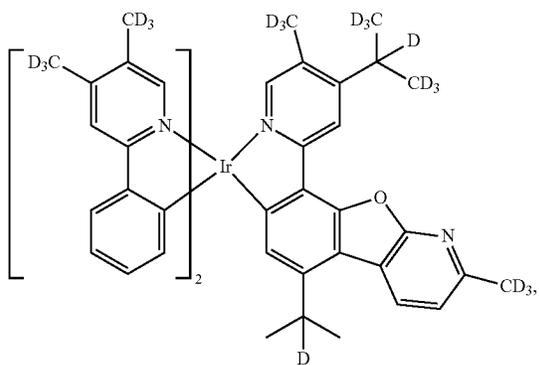
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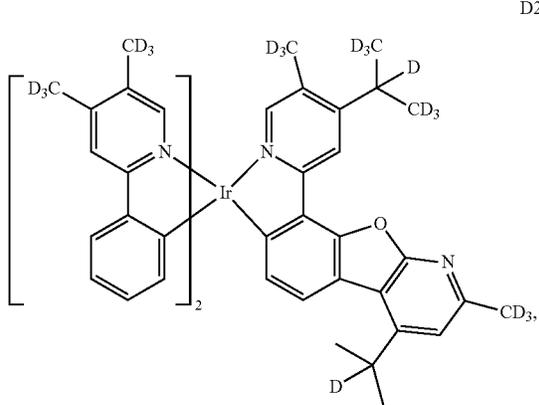
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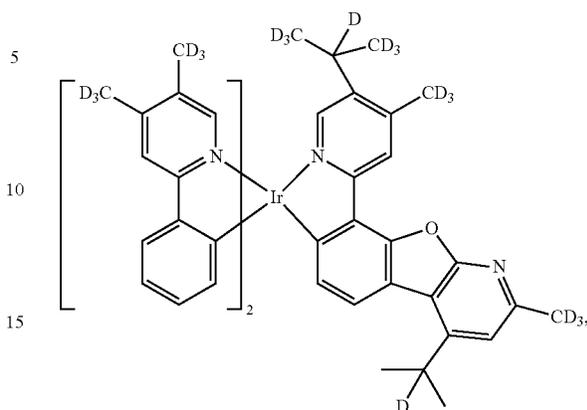
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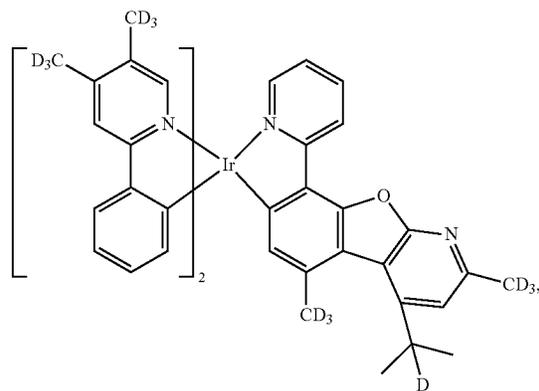
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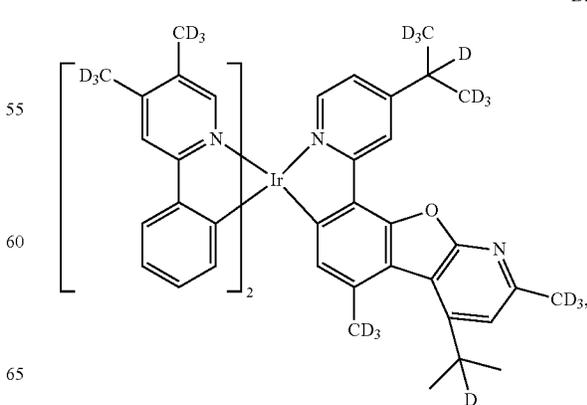
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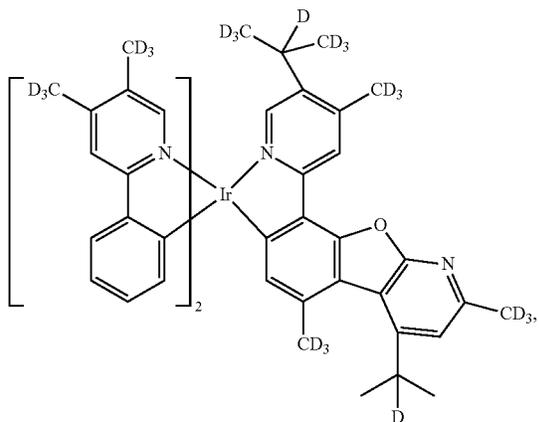
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D258



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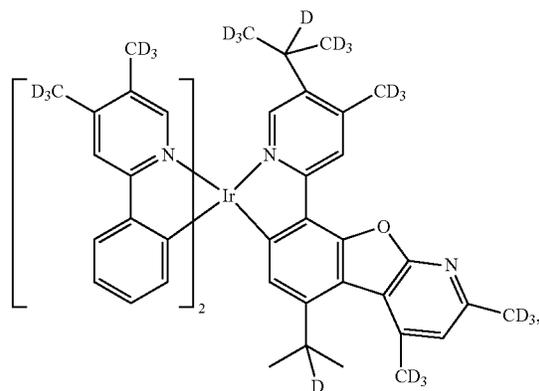
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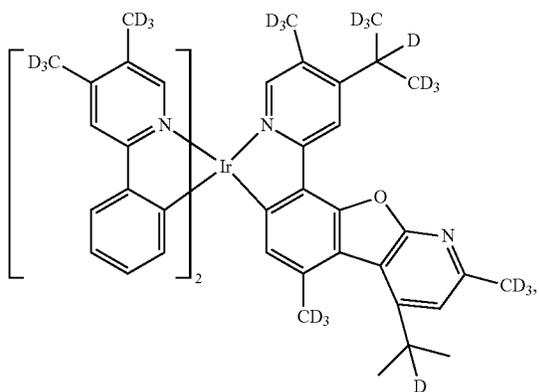
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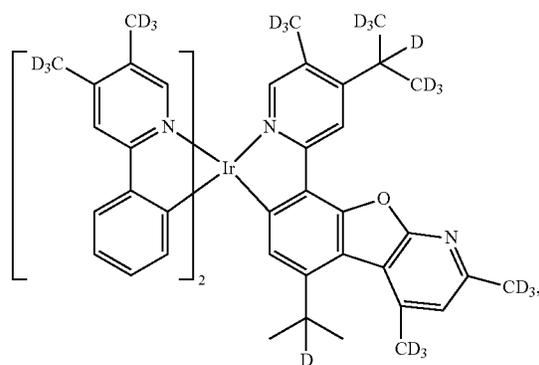
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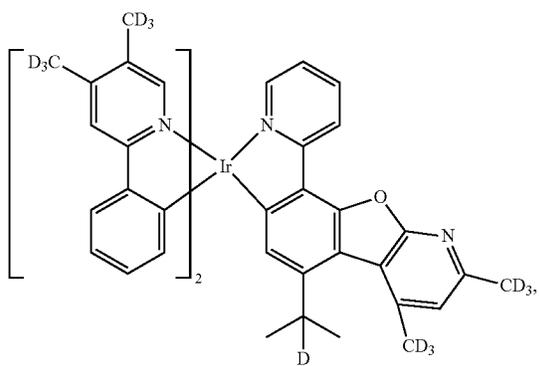
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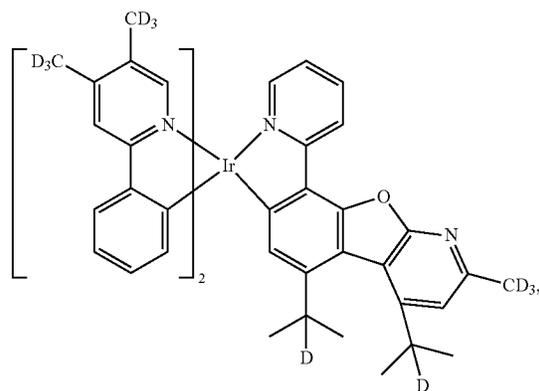
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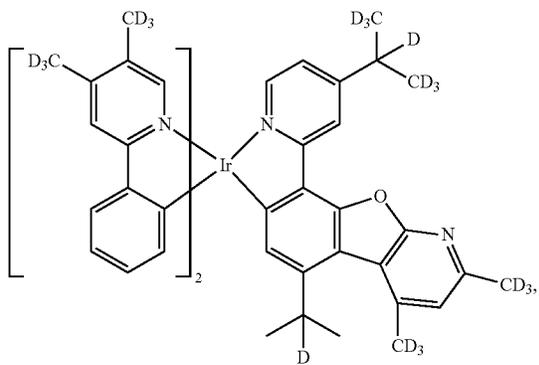
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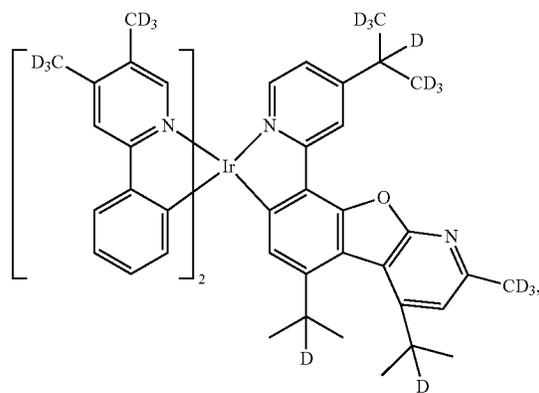
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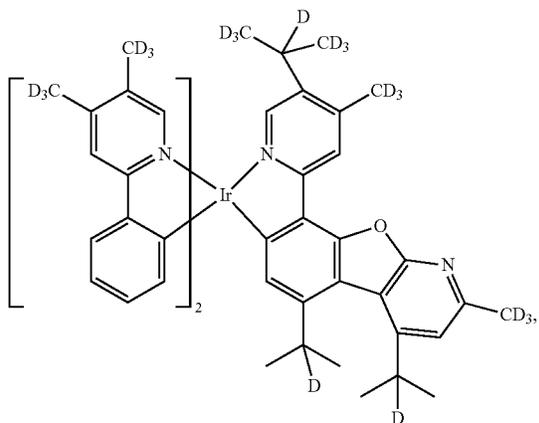
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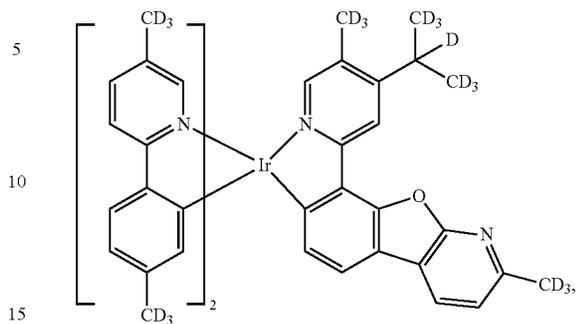
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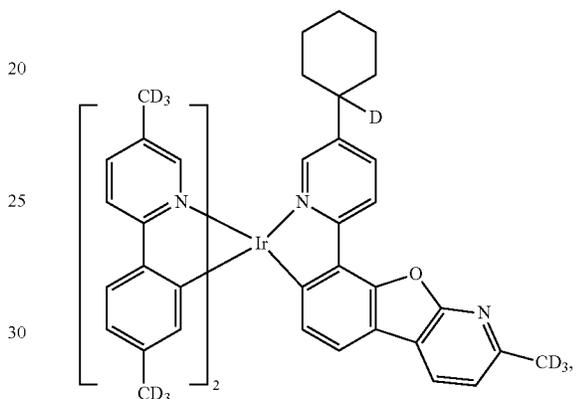
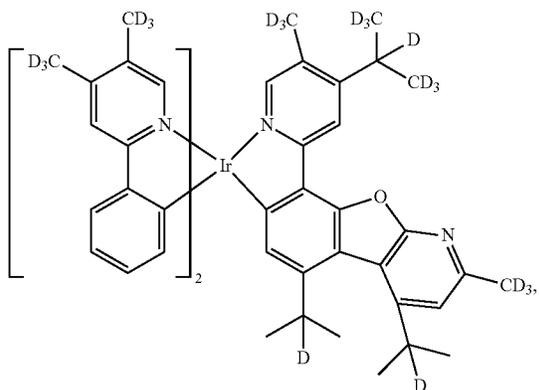
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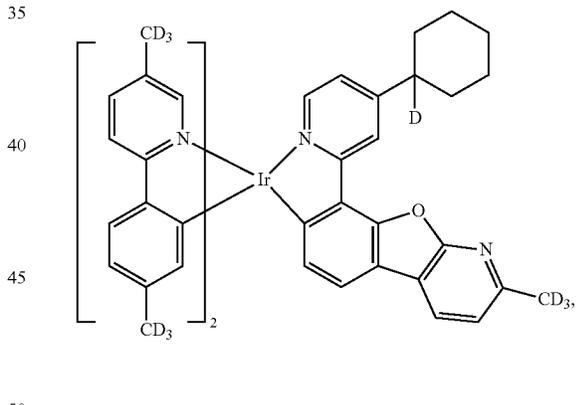
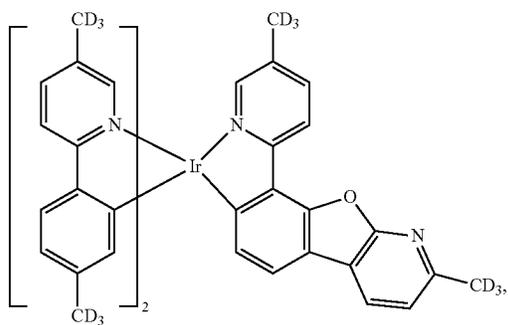


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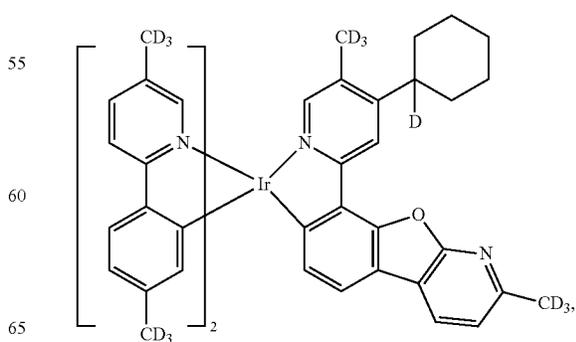
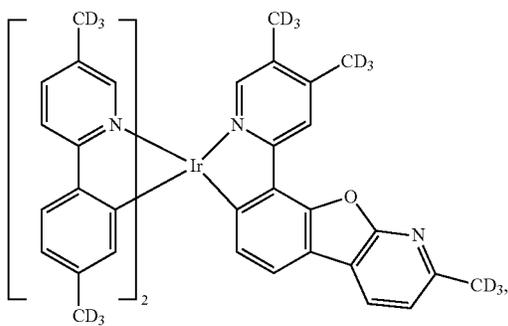
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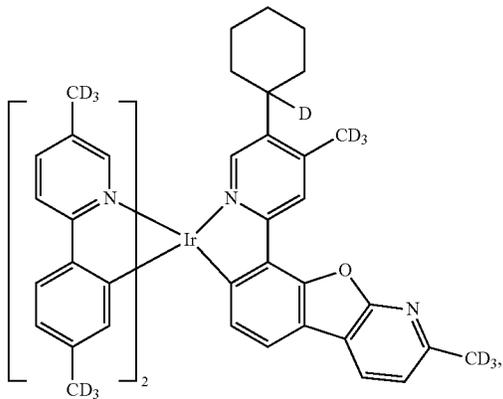
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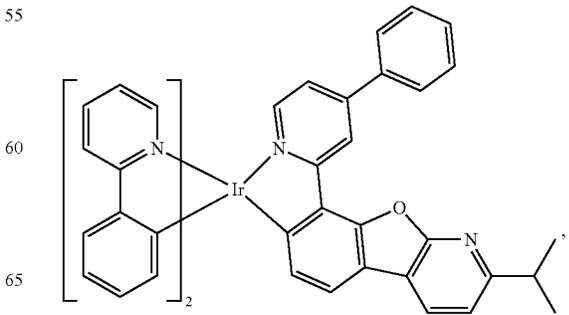
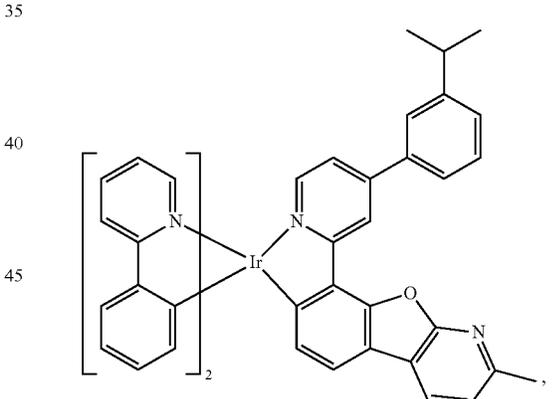
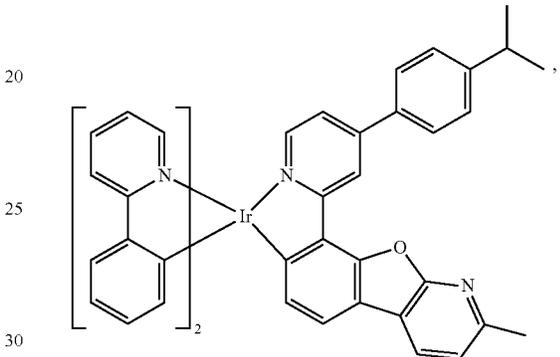
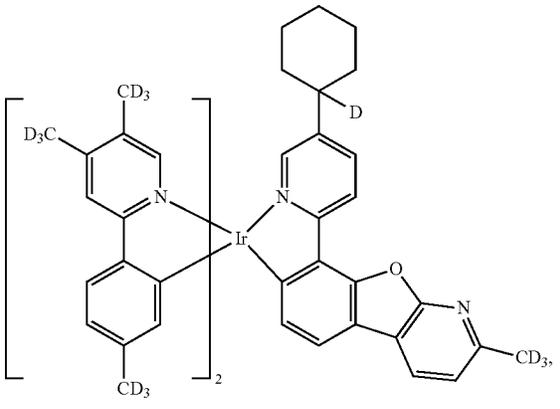
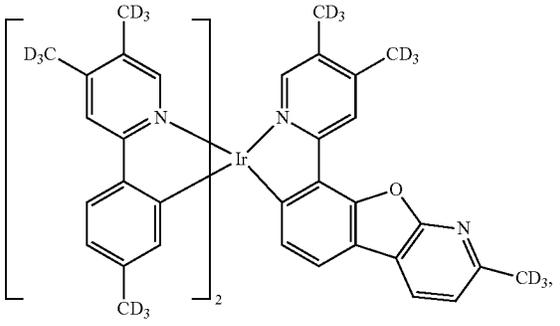
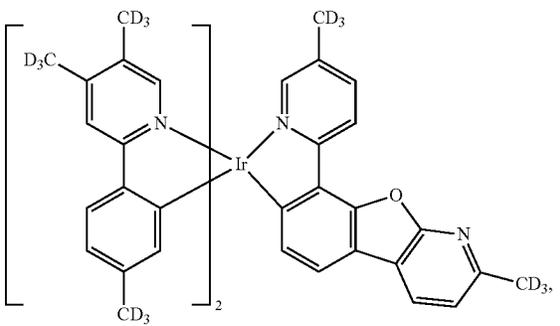
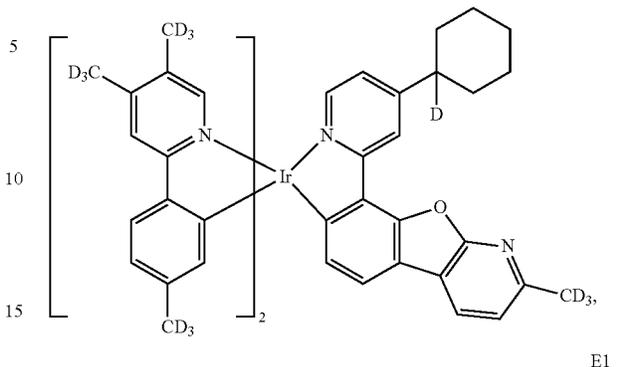
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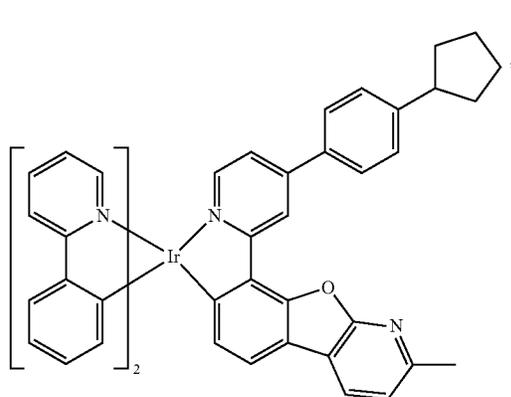
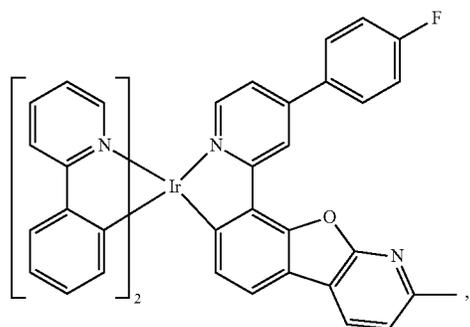
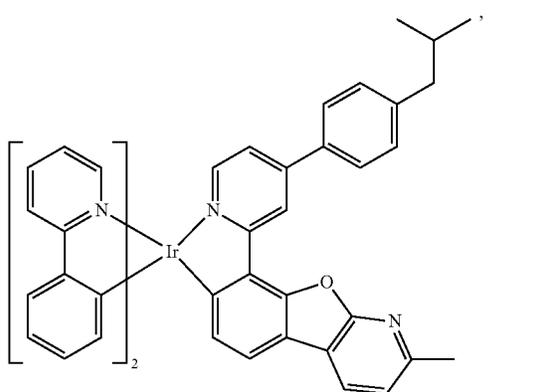
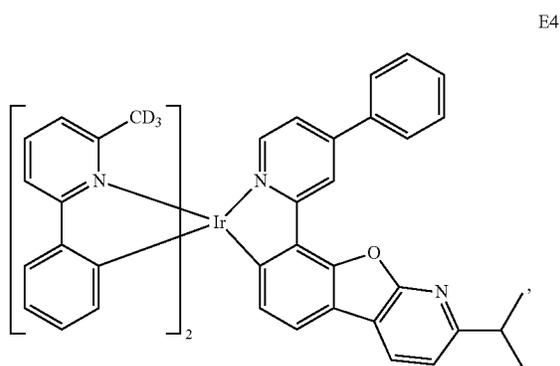
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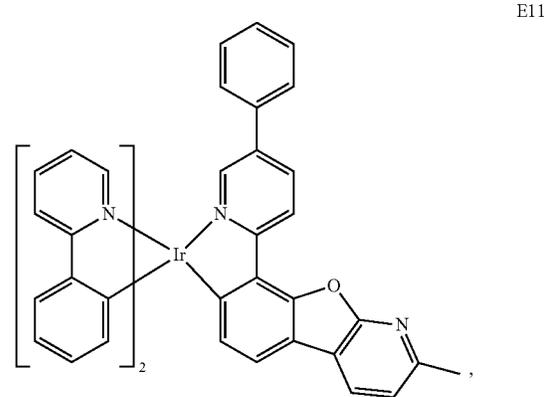
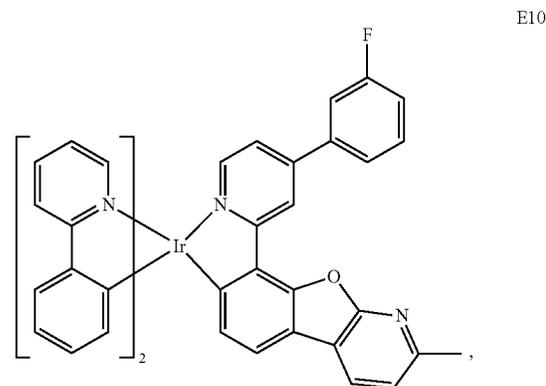
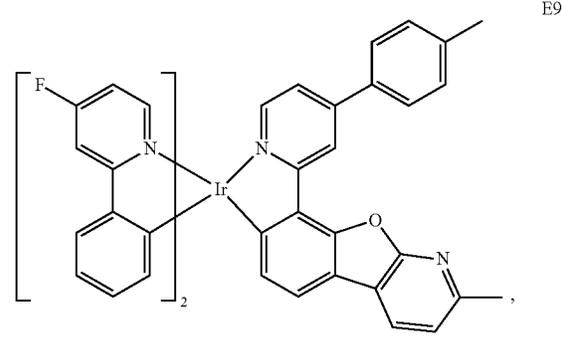
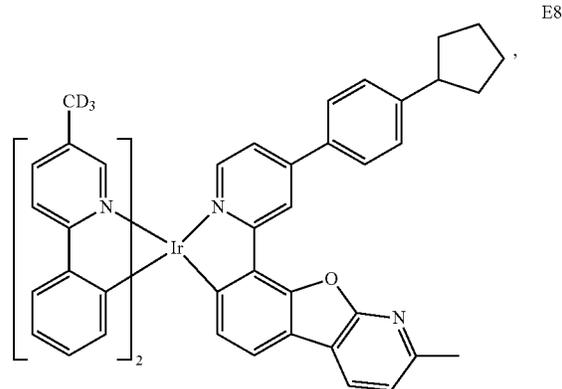
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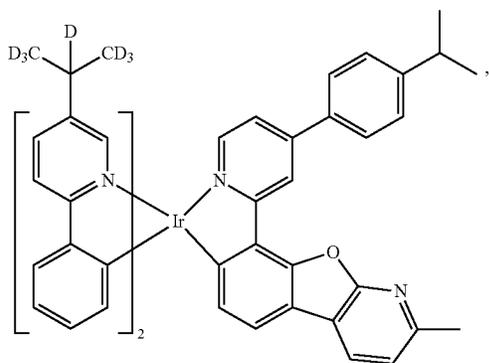
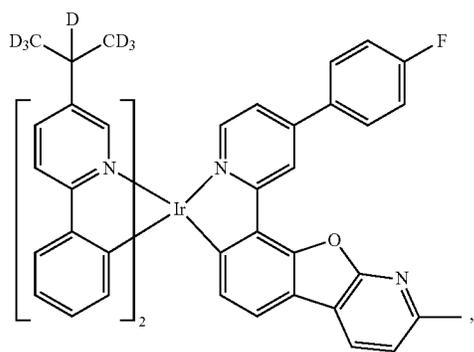
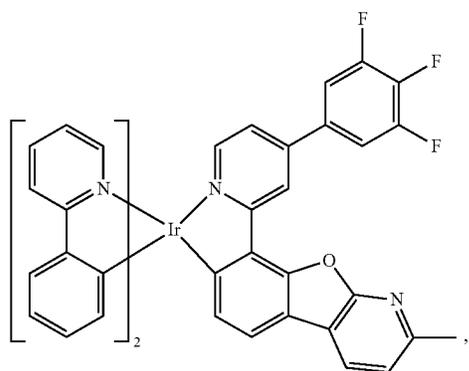
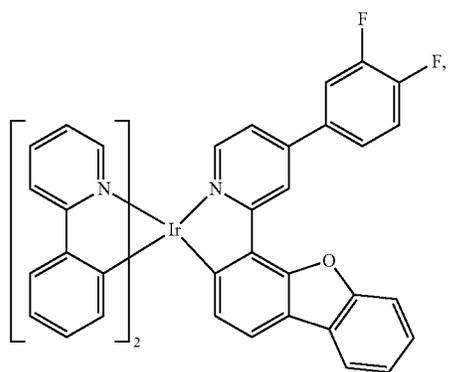
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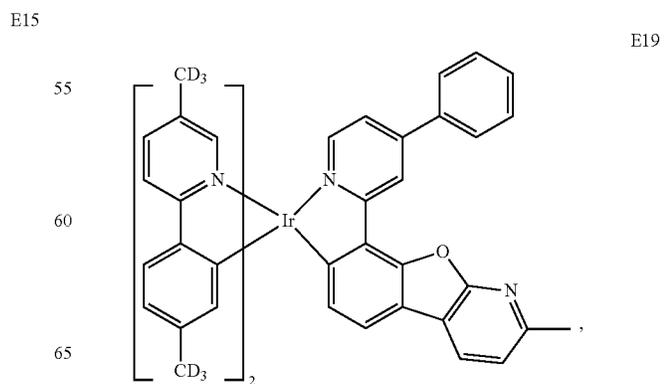
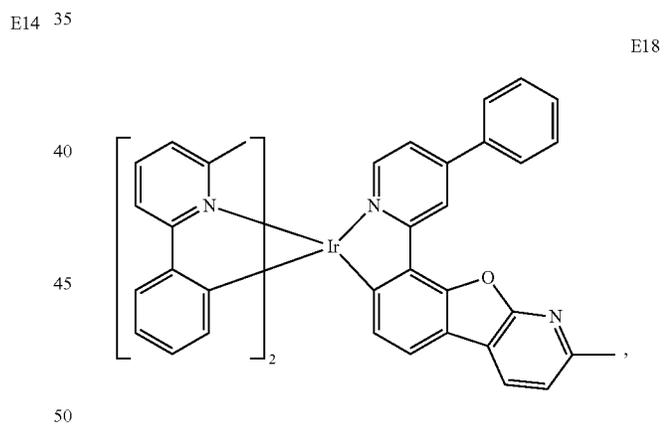
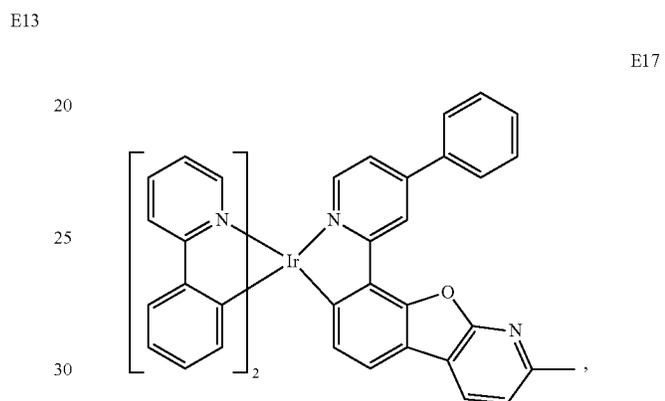
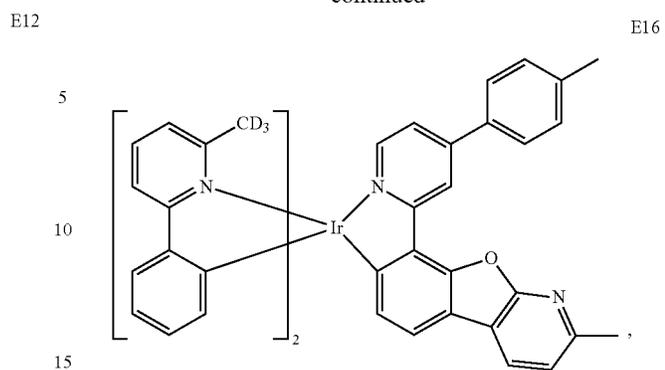
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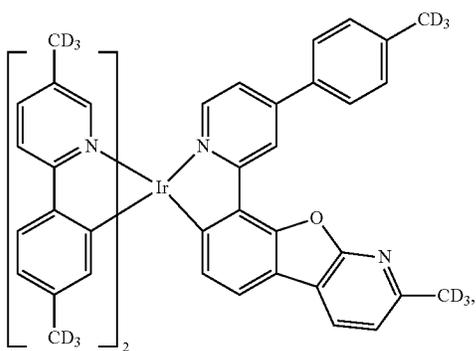


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**413**

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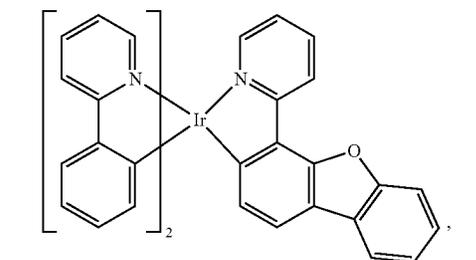
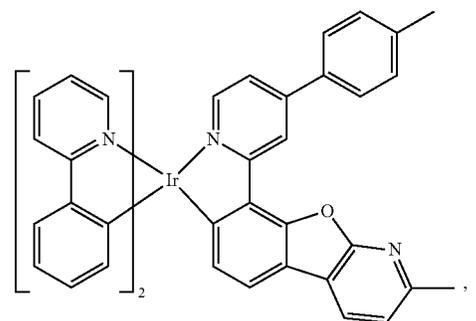
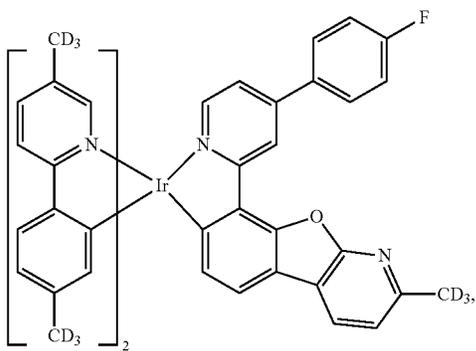
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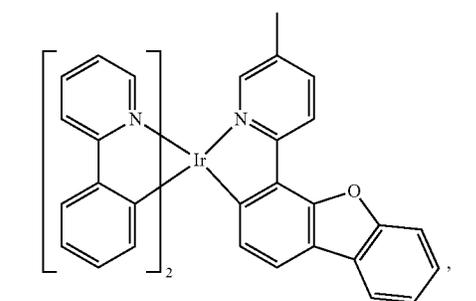
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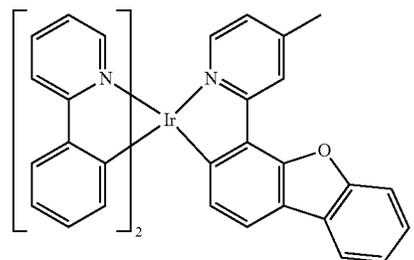
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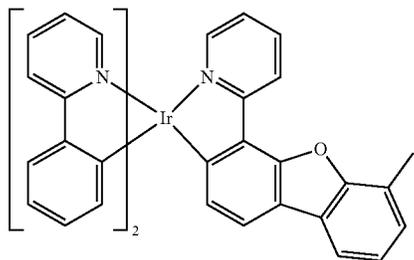
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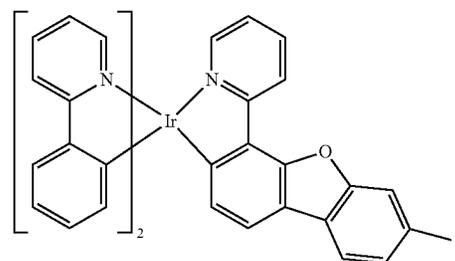
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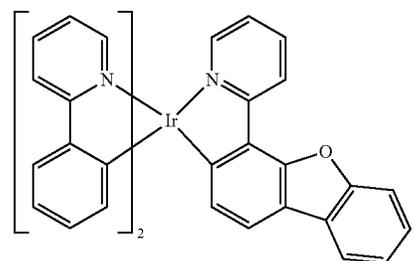
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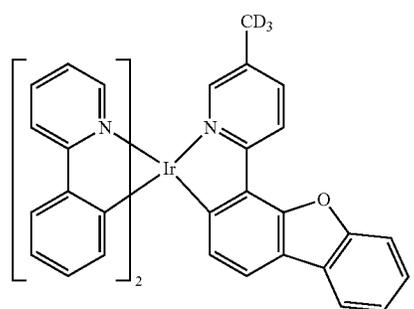
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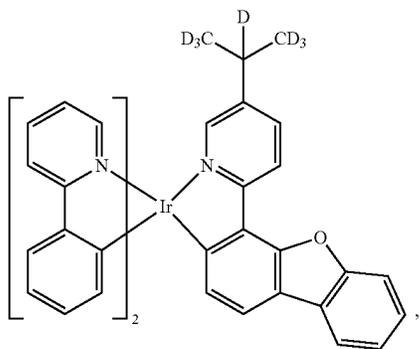
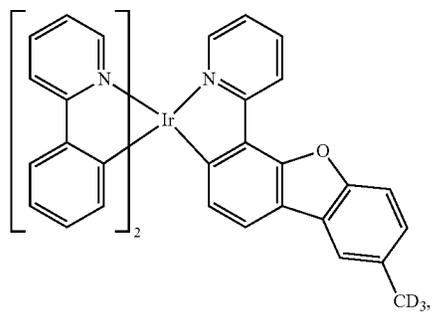
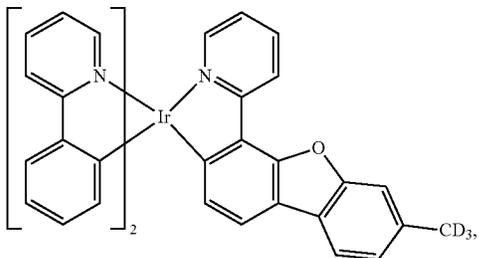
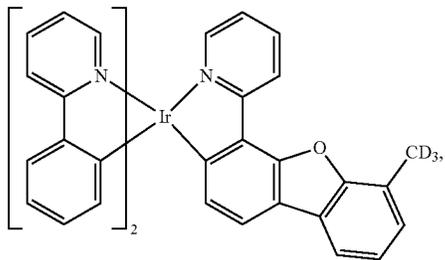
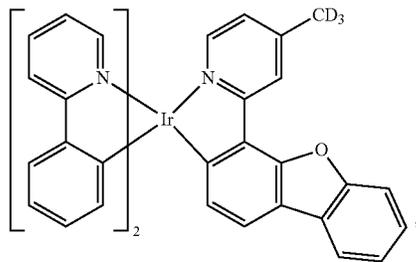
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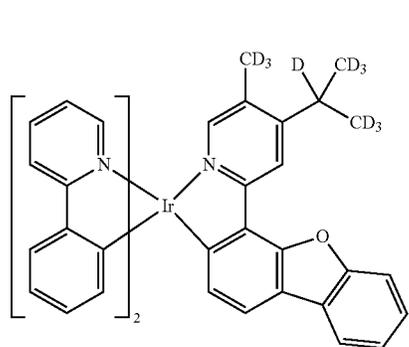
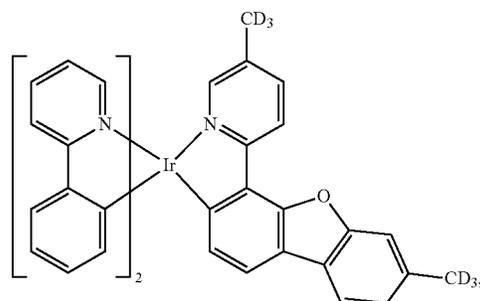
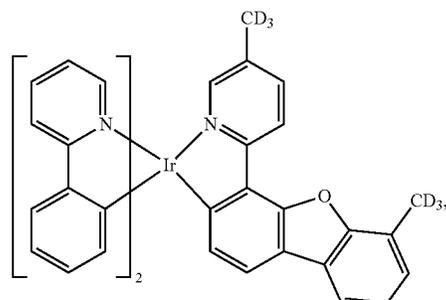
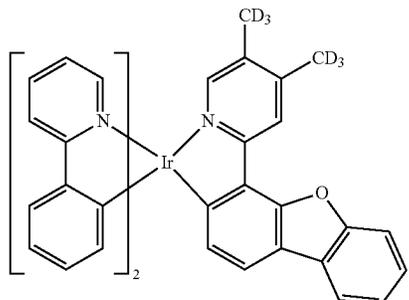
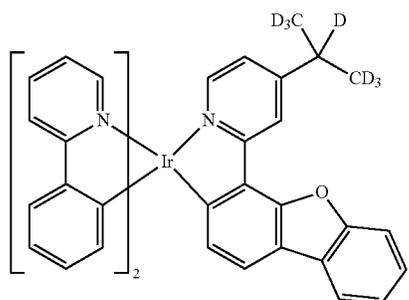
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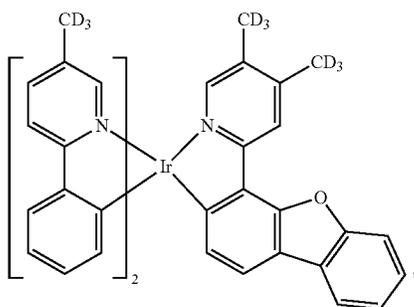
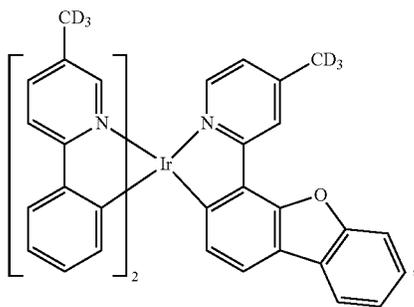
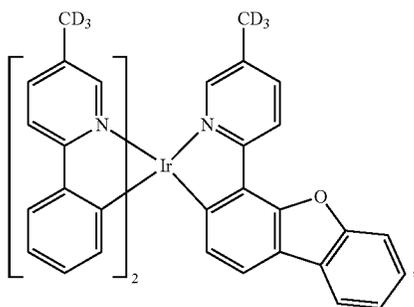
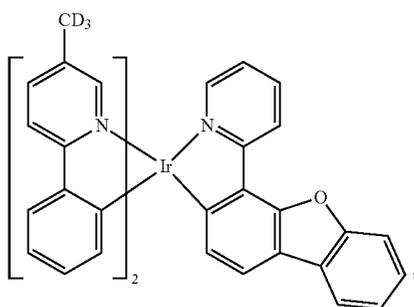
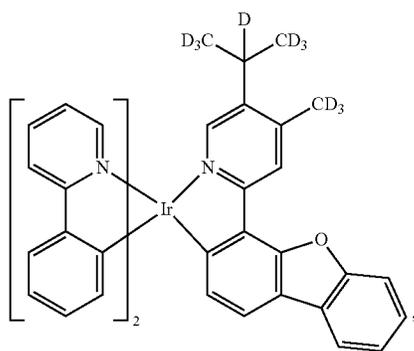
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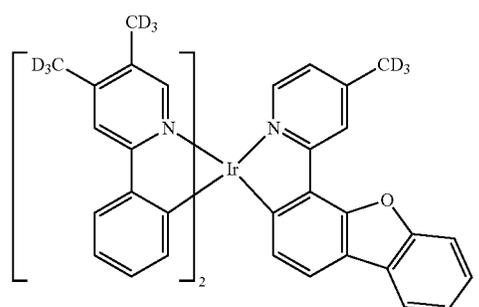
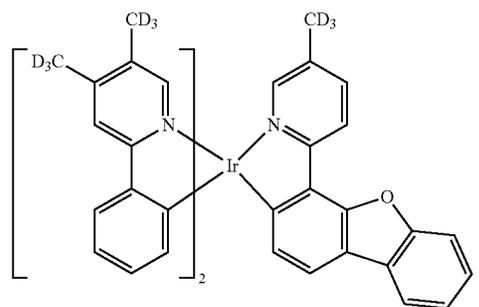
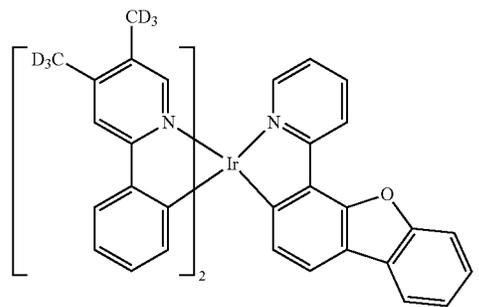
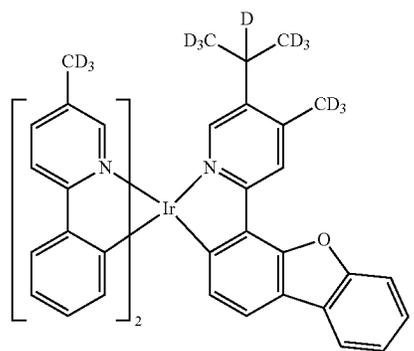
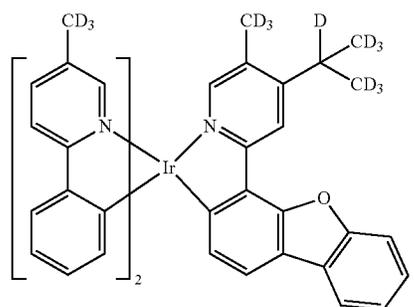
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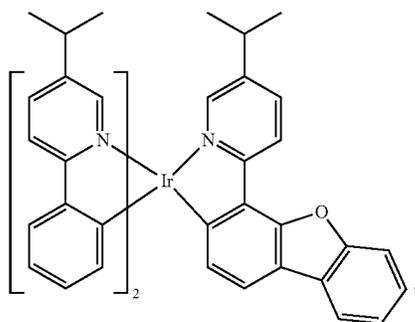
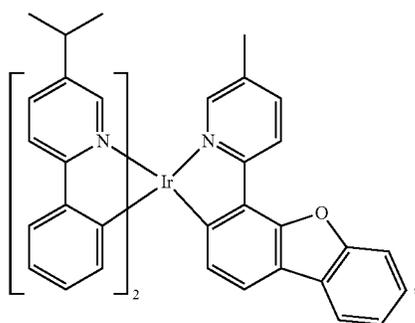
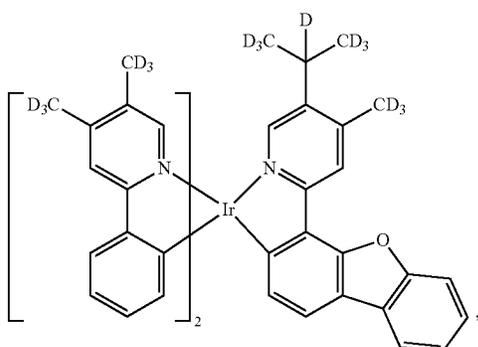
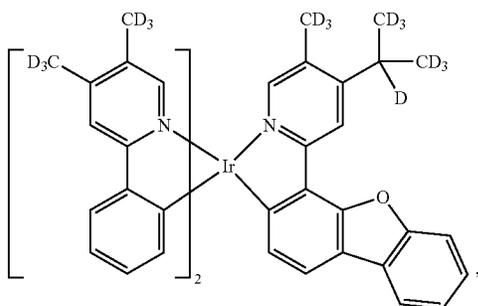
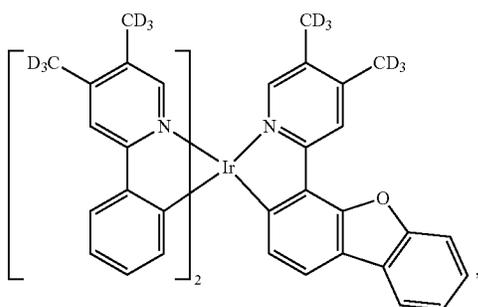
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F27



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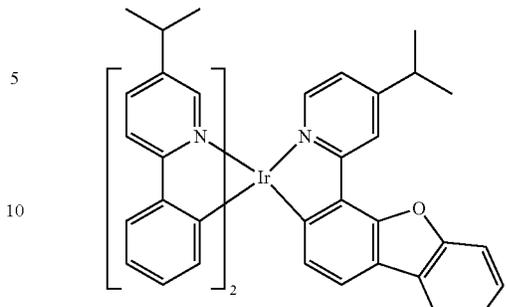
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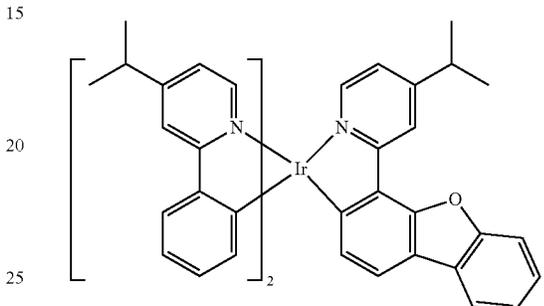
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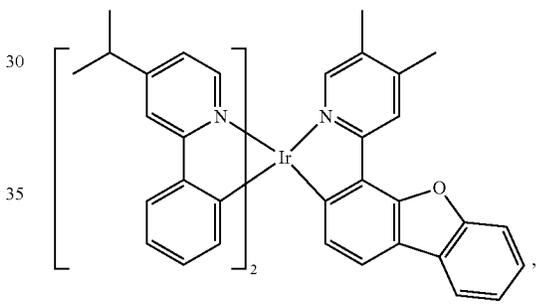
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F29



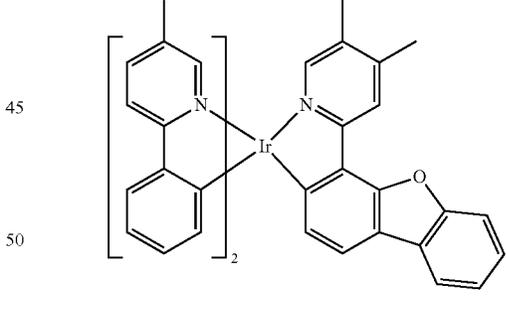
F34

F30



F35

F31



F36

F32

15. The composition of claim 1, wherein (a) X<sup>1</sup> or X<sup>2</sup> is present and represents Se.

16. The composition of claim 1, wherein (b)(1)(i) the first compounds has the structure of GH2 or GH3, and

(2) at least one of R<sup>1</sup> and R<sup>3</sup> is unsubstituted, and

(3)(i) G<sup>2</sup> is selected from the group consisting of dibenzoselenophene, phenanthroline, azadibenzofuran, azadibenzoselenophene, azafluorene, and combinations thereof.

17. The composition of claim 1, wherein (1)(ii) the first compound has a structure of GH1, GH4, or GH5, and two are not joined to form a ring, and

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**422**

- (2) at least one of  $le$  and  $R^3$  is unsubstituted, and
- (3)(i)  $G^2$  is selected from the group consisting of dibenzoselenophene, phenanthroline, azadibenzofuran, azadibenzoselenophene, azafluorene, and combinations thereof.

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